The LSC White Paper[1] on Education and Public Outreach

Goals, Status and Plans, Priorities (2013 Public v1 edition)

EPO group of the LSC[2]

December 6, 2013

[1] **Live Document! Please include "Tag P_Public-2013_v1" when referencing this version.**

[2] EPO E-mail: lsc-epo@ligo.org, EPO Wiki: http://wiki.ligo.org/EPO, and EPO White Paper Public Release in DCC: https://dcc.ligo.org/LIGO-T1300887

1 Synopsis

ïż£This review provides an all inclusive and illustrated description of the rich menu of possibilities of constructive EPO contributions to the LSC. The document also provides a precise description of EPO efforts from past deliveries to present commitments, and elaborates on the goals, philosophy, and plans of our international network of scientists unconditionally excited about public outreach, the EPO committee of the LSC. This is a living document that is updated frequently and is improved continuously.

If you know what you are looking for, here are some direct links to frequently accessed information about our efforts:

- If you are interested in our current work, please see Chapter 8
- If you are interested in our past achievements, please see Chapter 10
- If you are interested in the scope of our work, please see Chapters 5, 6, and 7
- If you are interested in our philosophy, please browse Chapter 3
- You can learn about our current priorities in Section 3.5.6 and Chapters 5, 6, 7

More than half of the research groups [1–46] in the LIGO Scientific Collaboration (LSC) [47] are actively involved in projects related to Education and Public Outreach (EPO). The main goal of the broader EPO team is to build on the excitement of LIGO's discoveries to engage the wider public beyond GW scientists, motivating students and increasing the scientific literacy of the general public.

Our motivations include the desire to:

- Arouse interest, attention, and motivation for outreach activities;
- Ensure that collaboration skills are optimally used to enhance the collaboration's public visibility;
- Coordinate the EPO activities of the LSC;
- Streamline and optimize the development and use of EPO resources;
- Create, facilitate, and nourish synergies among teams within and outside of the LSC;
- Interface EPO needs, goals, and objectives to the practical realities (e.g., prioritization, resource management, external hooks, etc.).

The broad, comprehensive, and inclusive nature of the long list of possible projects means that only a small fraction of the goals and possibilities can be pursued at any given time due to practical limitations. Nevertheless, it is expected that the rich set of exciting possibilities will attract new contributors and most projects will be covered during the next decade.

The EPO Committee is defined in the Bylaws [47] of the LSC as:

“. . .

7.13 Education and Public Outreach Committee

7.13.1 The Education and Public Outreach (EPO) Committee is responsible for overseeing and documenting the Collaboration's activities in education and public outreach. The EPO committee is also responsible for formulating the Collaboration's strategic plans to harness the excitement and enthusiasm generated by gravitational wave research in order to inspire and educate students and the general public in astronomy and fundamental science, and thus to help improve science literacy and education among the citizenry.

7.13.2 The EPO Committee consists of a chair appointed by the LSC Spokesperson, and at least four additional members from the LSC (including members from LIGO Observatories) with a spread of interests and expertise in formal and informal education, media relations, and in public and professional outreach.

7.13.3 The chair of the EPO Committee is appointed by the LSC Spokesperson for a term of two years. Other members of the EPO committee are appointed by the EPO chair for the term of her/his tenure in consultation with the LSC Spokesperson.

7.13.4 The EPO Committee is also responsible for preparing and maintaining a White Paper relevant to the Collaboration's plans and activities for education and public outreach, with an up-to-date version to be available before the beginning of the annual LSC MOU review cycle.

. . .”

LSC's outreach programs use a variety of means, methods and strategies to communicate cornerstone concepts to the public, including:

- Observatory-based activities such as site tours, school field trips and public events
- Public lectures and special events in community venues
- Delivery of in-school services such as classroom visits; participation in school career fairs and science nights
- Delivery of classroom visits remotely via videoconference
- Participation in local, regional and national science fairs, festivals and expositions
- Participation in multi-disciplinary events and programs such as science and the arts
- Hosting of filmmakers and writers who produce film, print and online materials for distribution through media outlets
- Development of an ever-expanding array of online and multi-media resources, including social media and online games and interactive activities
- Development and dissemination of formal education resources such as classroom lessons, instructional units and Web-based and print-based learning tools

- Delivery of extended experiences in areas such as robotics and computer programming through partnerships with school science clubs and after-school organizations

The LSC also seeks to strengthen the human resources associated with the science and engineering pipeline through sustained activities and programs, many of which occur in partnerships with like-minded organizations, including:

- Exhibiting and recruitment at diversity-oriented conferences and meetings
- Hosting of high school and undergraduate interns at LSC and LIGO Lab sites
- Hosting of K-12 teachers for summer internships
- Participation in K-12 teacher professional development programs
- Training and involvement of graduate students and post-docs in K-12 programs
- Participation as partners in externally-funded proposals and programs that deliver enhanced STEM resources to underserved K-12 populations

1.1 on Priorities, Figures of Merit, Mission

We describe a comprehensive list of beneficial projects that can be pursued by EPO sensitive teams and individuals. Consequently, we anticipate that only a small fraction of the possibilities shall be pursued at any given time. However it is expected that the outlined rich set of exciting possibilities will attract new contributors and most projects will be covered during the next decade. As a result, it might be helpful for contributors to offer a brief summary of the generic figures of merit, prioritization principles, and encouragement to collaborate.

The fundamental figure of merit for an education and outreach project is the number of minds touched and reached. This quantity can be maximized in many different ways, from deep one-by-one teaching experiences, through "teaching the teachers", to global media broadcasting. All of these tactics and approaches have advantages and disadvantages, the most prevalent is the seeming uncertainty relation between the size of the audience and the allotted time to reach them, e.g., usually a long time is available in a small group teaching environment but the number of students is severely limited, while a BBC radio broadcast can reach tens of millions of receptive minds, but the time available to accomplish this task can be measured in minutes - and may be subject to the vagaries of external editorial control.

All EPO contributors are strongly encouraged to favour and to choose projects where their effort can reach and benefit the largest number of minds. Consequently, projects that deliver the best performance in this respect will be given higher priority, should be pursued preferentially, and must get most support from the EPO team as a whole. Therefore it is crucial that project initiators provide an impact analysis that is as realistic and precise as possible when proposing a new team-based project.

There are many forms of collaboration that are beneficial to EPO, and most projects we pursue can be improved through collaborative tactics. Nevertheless it is important to emphasize that coordination should only be replaced by collaboration if the " **the whole is a lot more than the sum of the parts**"; otherwise the inevitable delay and overhead of collaborative work can take away all the benefits of the work. Four basic examples of fruitful collaboration types with great potential benefits for engaging the entire EPO team are: (a.) expert advising, (b.) community brainstorming, (c.)

distributed contribution to generate a common product, and (d.) pooling of special talent/expertise to enable us to accomplish a task none of us are able to tackle alone. Since collaborations can often maximize our figure of merit, EPO members are strongly encouraged to join or initiate collaborations that can result in a better final product than working alone.

Often times exceptional individuals can maximize their EPO impact themselves at tasks where collaboration does not help. Nevertheless, even in these cases the EPO forum is critical for the LSC team, as it provides an opportunity for these individuals to share their experiences, and thus teach the team the winning tactics and strategy, or simply to provide scalable resources and expertise, that can spawn future exceptional EPO success either through individual or group contributions.

Contents

2 Introduction

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.

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.

2.1 Projects, Initiatives, and Ideas; A Global Overview

Our goal is to convey the knowledge, excitement, and potential of the field of Gravitational-wave Astrophysics to the public of all ages, occupation, and preparation. Successes of the past, contributions of the present, and ideas for the future are summarized visually in Figures 2.1, 2.2, 2.3, 2.4. Past results on a subset of topics are highlighted and summarized in Appendix 10, present commitments are detailed in Chapter 8, and plans+opportunities for the future are described in Chapters 3.5.6, 6, 5, 7.

2.1.1 Graphical summary of the current scope of ongoing and foreseen EPO activities

EPO Committee and Coordination

The EPO Committee coordinates the work of the following groups, projects and initiatives:

- MoU Review, Reporting, Coordination
- Press/Media Relations
- White Paper Editions
- Compilation of Statistics, Efficacy, Performance Measures
- Award, Prize, Fellowship Surveys and Highlights
- R&D on Effective Communication
- R&D on EPO and Outreach Innovation
- GW History Project
- Formal Education Group
- Informal Education Group
- Professional Outreach Group
- National and International Partnerships

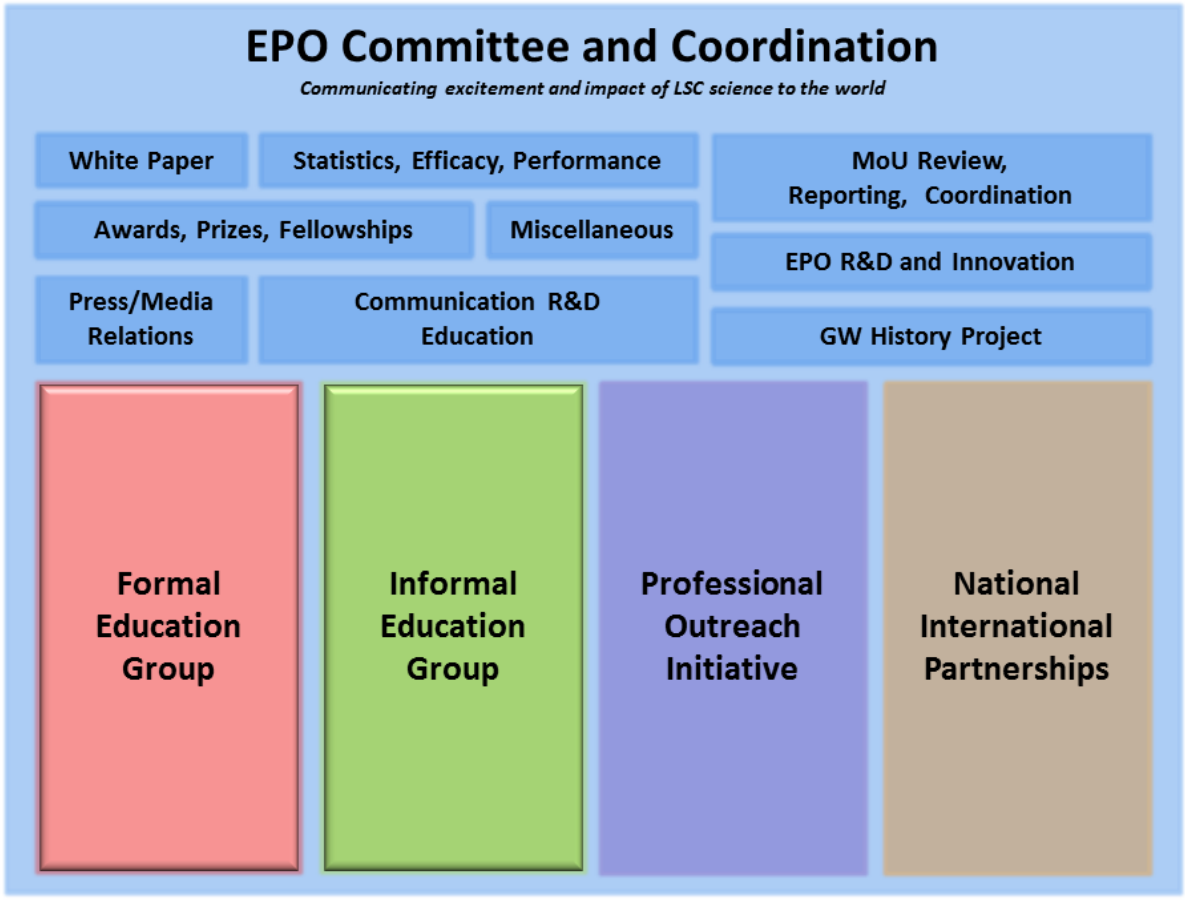

Figure 2.1: The goal of the EPO Committee is to communicate the excitement and impact of LSC science to the world

EPO Formal Education Group

The EPO Formal Education Group is responsible for the work of the following projects and initiatives:

- **For Elementary School Students**
- Support & Involve Ages: 4 - 7
- Support & Involve Ages: 7 - 12
- GW Picture Books
- Curriculum Development
- **For Middle and High School Students**
- Activities, Demos, and Events
- Talks and Lectures

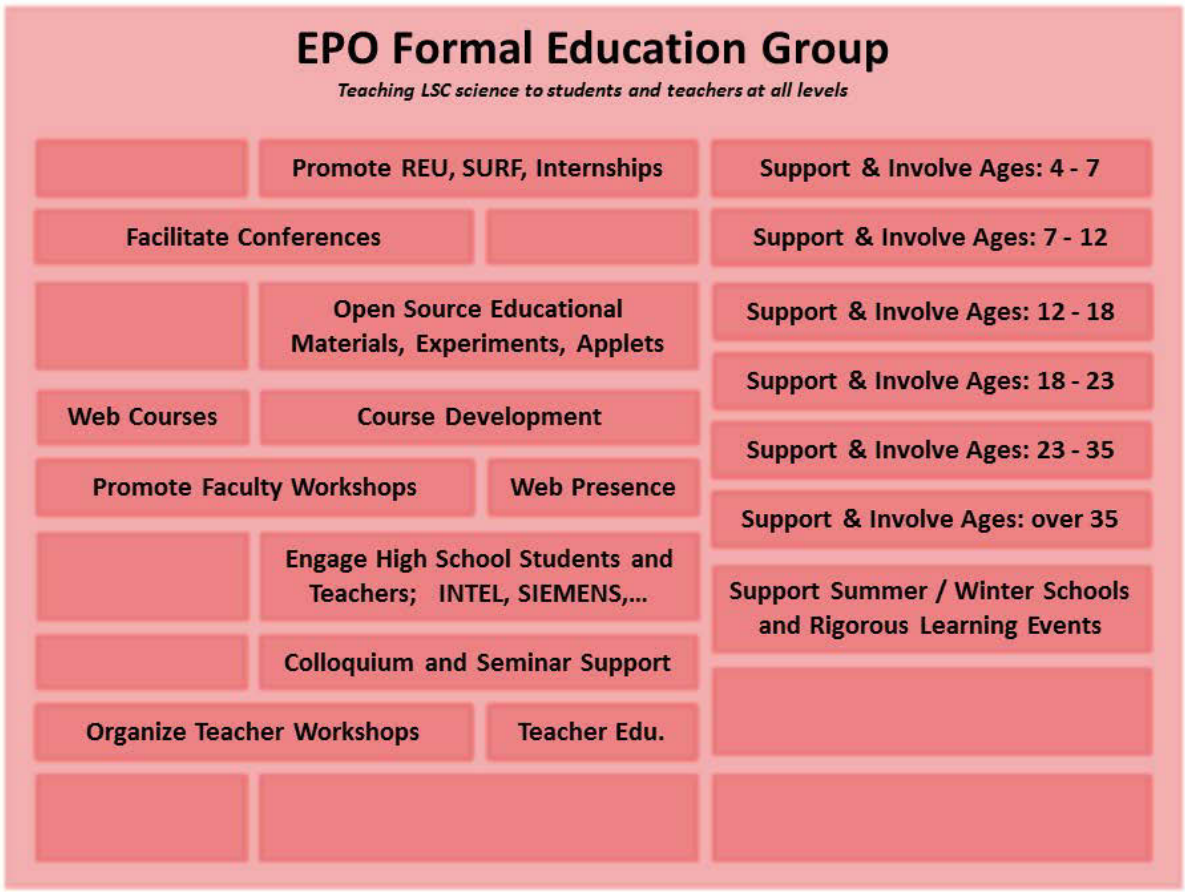

Figure 2.2: The goal of the EPO Formal Education Group is to teach LSC science to students and teachers at all levels.

- Summer Programs
- Research Involvement
- "Office Hours" with LIGO Scientists
- Curriculum Development
- **For University Students**
- Promote and Support REU, SURF, Undergraduate Research
- Support Summer / Winter Schools and Rigorous Learning Events
- Colloquium and Seminar Organization, Placement, and Support
- Distribution of Video Recordings of Talks
- Web Materials

- Curriculum Development
- **For Educators**
- Promote Faculty Workshops
- Teacher Education Initiatives
- Organize Teacher Workshops
- Unified Teacher Materials Hub
- **For All**
- Support & Involve Ages: 18 - 23
- Support & Involve Ages: 23 - 35
- Support & Involve Ages: over 35
- Lectures/talks/festivals/expo
- Create Open Source Educational Materials, Experiments, Applets
- Web Courses
- **Other**
- Facilitate Conferences
- Web Presence

EPO Informal Education and Outreach Group

The EPO Informal Education and Outreach Group coordinates the work of the following projects and initiatives:

- **Toys and Goodies**
- T-Shirts
- Toys
- Posters and Stickers
- Origami
- LEGOs
- **Visual Media**
- Comics
- Cartoons

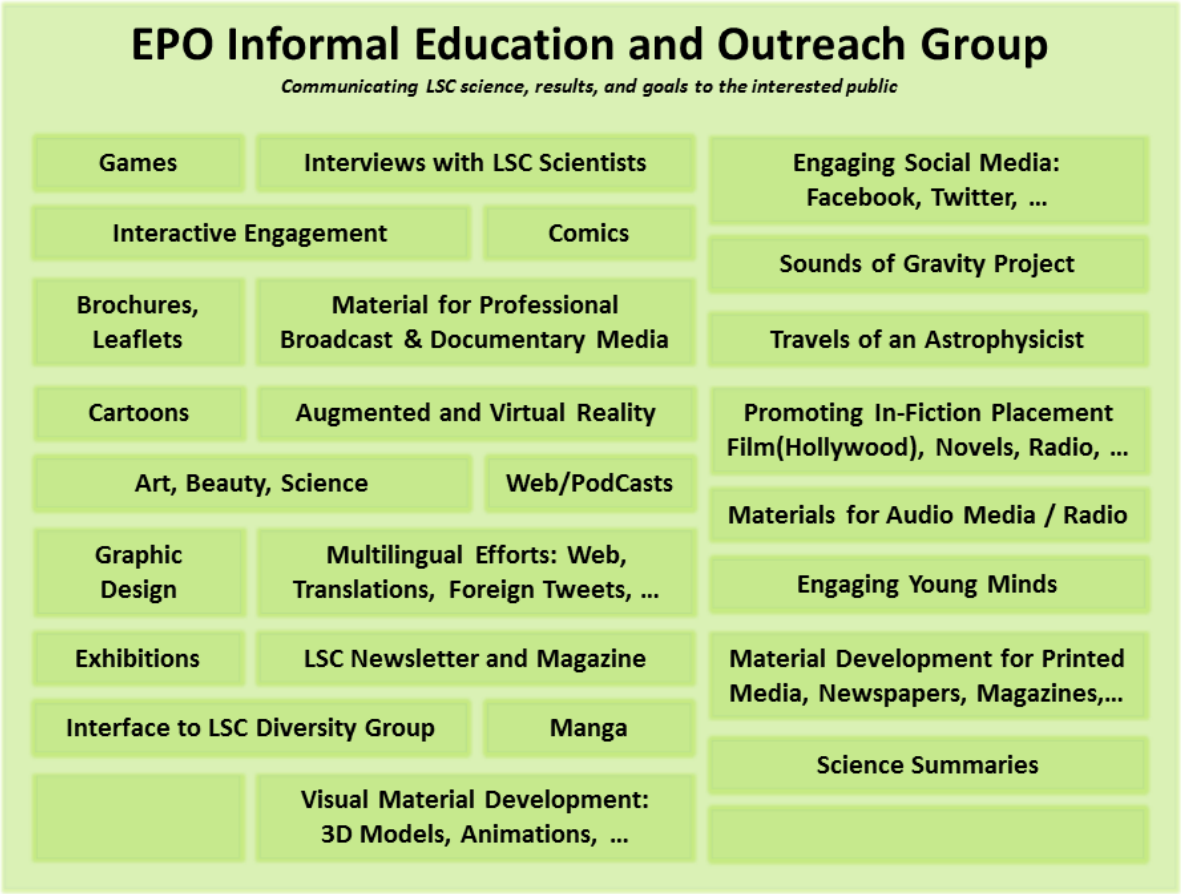

Figure 2.3: The goal of the EPO Informal Education and Outreach Group is to Communicate LSC science, results, and goals to the interested public.

- "Art, Beauty, Science" Project
- Graphic Design
- Visual Material Development: 3D Models, Animations, and others
- Manga
- Slideshows
- **Audio Media**
- "Sounds of Gravity" Project'
- Development of Materials for Audio Media / Radio
- Creative Musical Projects

- Development of Web/PodCasts
- Promoting Radio Placement of our Field
- **Film, Video, Animations**
- Development of Materials for Professional Broadcast & Documentary Media
- Promoting Film(Hollywood) Placement of our Field
- Development of Educational Videos for Web Publication
- **Interactive Media**
- Develop and Promote Games
- Expansion to Multiple Platforms: iPhone apps, Android apps
- Development of Augmented and Virtual Reality
- Developing, Organizing, and Providing Exhibitions
- Science Museums and Planetariums
- **Print Media**
- Development of Brochures and Leaflets
- Promoting In-Fiction Placement of our Field
- Material Development for Printed Media, Newspapers, Magazines, and Others
- Supervising Science Summaries
- Publishing LSC Newsletter and Magazine
- **Performance Art**
- "Einstein's Cosmic Messengers" Solo Performance
- "Astrophysics and Dance"
- Spoken Word
- **Up Close and Personal: Meet the Scientists**
- Interviews with LSC Scientists
- "Travels of an Astrophysicist" Project
- Blogs By LSC Scientists
- Guided Tours
- **Expanding Our Audience**

- Engaging through Social Media: Facebook, Twitter, and Others
- Multilingual Efforts: Web, Translations, Foreign Tweets, and Others
- Interfacing to LSC Diversity Group
- Recruitment
- New Websites
- **Other**
- "Engaging Young Minds" Project

EPO Professional Outreach Initiative

Figure 2.4: The goal of the EPO Professional Outreach Initiative is to communicate LSC science, results, and expertise to professional organizations, colleagues, and the deeply interested public

The EPO Professional Outreach Initiative coordinates the work of the following projects and initiatives:

- **Internal Education**
- Teach LIGO to LSC members and Other Professionals
- Teach the Art of Funding
- Outreach Abstracts
- Teach Effective Communication
- Interface to LSC entities: WebCom, P&P, LAAC, and Others
- Dictionary & Handbook Project
- **For Broader Scientific Community**
- APS, AAS, AAAS, IEEE, OSA, and others
- Facilitate Employment, Recruitments, and Conferences
- Professional Tutorials through Web, Radio, WebCasts, PodCasts
- GWIC
- Software Tools
- **For Amateur Scientists**
- Distribution of Environmental Data; Enable Access and Use
- Engage, Excite, and Facilitate Amateur and Citizen Science
- Facilitate Crowd Sourcing
- **For General Public**
- Printed/Broadcast Media
- Highlight Spinoff Tech
- Development of Professional Exhibits
- **Other**
- Enable and Facilitate Industrial and Corporate Relations
- Facilitate/Provide Science Interpretation for Policy Making

3 Essays on Structure, Goals, and Philosophy

This document is the 2013-14 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 committee of the LSC, an international network of scientists interested in public outreach. This document is revised and updated every year in the Summer, and is finalized by early Fall. In the spirit of other LSC white papers, the purpose of this document is to:

- Provide interest, attention, and motivation for outreach activities;
- Ensure that collaboration skills are optimally used to enhance the collaboration's public visibility;
- Coordinate the EPO activities of the LSC;
- Streamline and optimize the development and use of EPO resources;
- Create, facilitate, and nourish synergies among teams within and outside of the LSC;
- Interface EPO needs, goals, and objectives to the practical realities (e.g., prioritization, resource management, external hooks, etc.).

3.1 Executive Summary

During the next several years, we expect Advanced LIGO (aLIGO) to become operational, directly detect the first gravitational waves (GW), and pioneer gravitational-wave astrophysics. These initial detections are expected to generate a tremendous amount of public interest in gravitational-wave astrophysics in general and LIGO in particular - their dreams, goals, discoveries, science, technologies and scientists.

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.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 team 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 team 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.

Figure 3.1: LIGO scientists like J. Berliner reach unique places in their free time and spread the word about the science and excitement of experimental gravitational wave science.

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

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.

Collaboration outreach has been a part of the LIGO project since the completion of site construction and always on the level of the individual researcher. The level of outreach has steadily increased from early good will development to serious programs reaching tens of thousands, sometimes millions, 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 committee 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.

A 2004 National Science Foundation outreach award resulted in the creation of the LIGO Livingston Science Education Center (SEC). Southern University, The Exploratorium, Louisiana Systemic Initiative Program and Louisiana GEAR UP partnered with LIGO on the SEC proposal and the resulting development of the SEC as a premier science education resource in the southeast U.S. The SEC now draws hundreds of teachers and thousands of students and adults annually. SEC staff

members also extend their outreach efforts into community venues, impacting thousands that may not be able to visit the observatory personally. The partner-based structure of the SEC continues to expand. Tulane University, the Baton Rouge Area Foundation (BRAF), several school districts and the University of South Florida have become SEC partners. Currently LIGO and its collaborators are developing a stronger understanding of how the general public learns about science as the SEC continues its effort to elevate science literacy in Louisiana. The Science Education Center is close to its maximum capacity of K-12 student groups that visit per year, and is nearing saturation for the K-12 teacher professional development. A steady stream of fresh and engaging opportunities at the facility has created a high retention rate of schools and teachers. Careful, thoughtful and creative management will be needed to ensure that the SEC retains a high-impact position in the education landscape of Louisiana.

LIGO Hanford Observatory's public outreach program strongly resembles LIGO Livingston's in methods and objectives. Like the SEC, LIGO Hanford (LHO) serves a large population of students and families from groups that are underrepresented in STEM professions. The majority of residents in Franklin County near LHO are Hispanic/Latino. A number of schools that visit LHO each year possess student populations that exceed 70% Hispanic. Such students typically comprise 40-45% of the 1700 annual K-12 visitors to the site. In 2012, another 1700 general public visitors will visit LHO for public tours, privately scheduled tours, public astronomy events and other special activities. Currently LIGO Hanford reaches another 7000 students and adults through off-site engagements such as visits to schools and community events. A two-week Washington State University Tri-Cities graduate course for teachers, The *Nature of Scientific Inquiry*, remains the centerpiece of Hanford's teacher professional development efforts. LHO and its outreach partners remain vigilant for opportunities to submit proposals that will support the broadening and deepening of outreach to teachers.

The activities of the LSC EPO group are varied and wide-ranging. Each activity represents a different approach to engaging 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 enhance the clarity, accuracy, and validity of the information on Internet, members of the EPO team participate in an activity called the "Blog Squad" in which LSC EPO members rapidly assess and if necessary respond to 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 interactive 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) [48].

In addition to reaching out to 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.

3.2 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 about 800 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 now the LSC comprises of more than 50 research groups and more than 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, Ger-

many, 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. **??** (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`.

3.3 Participating LSC institutions with outreach MOU

As of Fall 2012, more than 40 LSC groups [1–46] have signed outreach MOU attachments, including:

- Contact: David Mcclelland; Australian Consortium for Interferometric Gravitational Astronomy
- Contact: Joshua Willis; Abilene Christian University
- Contact: Greg Harry; American University
- Contact: Tiffany Summerscales; Andrews University
- Contact: Alicia Sintes; Balearic Islands Relativity and Gravitation Group
- Contact: Andreas Freise; The University of Birmingham
- Contact: Nelson Christensen; Carleton College Relativity Group
- Contact: B. Sathyaprakash and Bernard Schutz; Cardiff University
- Contact: Yanbei Chen; Caltech Relativity Group
- Contact: Kipp Cannon; Canadian Institute for Theoretical Astrophysics and Perimeter Institute for Theoretical Physics
- Contact: Eugeniy E. Mikhailov; College of William&Mary
- Contact: Szabolcs Marka; Columbia University in the City of New York
- Contact: Michele Zanolin; Embry-Riddle Gravitational Wave Astrophysics Group
- Contact: Zsolt Frei; Eötvös Loránd University
- Contact: Joshua Smith; California State University Fullerton
- Contact: Karsten Danzmann and Susanne Milde; Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Potsdam, Germany

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

- Contact: Martin Hendry; University of Glasgow
- Contact: Steven Penn; Hobart and William Smith Colleges
- Contact: Hyung-Mok Lee; Korean Gravitational wave Group - Seoul National University
- Contact: Laura Cadonati; University of Massachusetts - Amherst item Contact: Roy Williams; LIGO Laboratory, Caltech
- Contact: Fred Raab and Dale Ingram; LIGO Hanford Observatory
- Contact: William Katzman; LIGO Livingston Observatory
- Contact: Gabriela Gonzalez; Experimental Relativity Group of the Louisiana State University
- Contact: Marc Favata; Montclair State University
- Contact: Vassiliki Kalogera; Northwestern University Gravitational Wave Astrophysics Group
- Contact: Ben Owen; Pennsylvania State University Relativity Group
- Contact: John Whelan; Rochester Institute of Technology
- Contact: Peter Beyersdorf; San Jose State University
- Contact: Lynn Cominsky; Sonoma State University
- Contact: Ian Jones; University of Southampton
- Contact: Stephen McGuire; Southern University and A&M College
- Contact: Troy Williams; Southeastern Louisiana University
- Contact: Robert Byer and Brian Lantz; Stanford Advanced Gravitational Wave Interferometry Group
- Contact: Duncan Brown; Syracuse University Gravitational-Wave Group
- Contact: Dennis Ugolini; Trinity University
- Contact: Guido Mueller; University of Florida LIGO Group
- Contact: Alessandra Buonanno and Peter Shawhan; Maryland Gravitational-Wave Group
- Contact: Keith Riles; Michigan Gravitational Wave Group
- Contact: Marco Cavaglià; University of Mississippi
- Contact: Ray Frey; University of Oregon Experimental Relativity Group
- Contact: Ed Daw; The University of Sheffield
- Contact: Mario Diaz; University of Texas at Brownsville
- Contact: Shane Larson; Utah State University
- Contact: Patrick Brady; University of Wisconsin–Milwaukee
- Contact: David Blair; University of Western Australia

3.4 Funding Opportunities, Options, and Sources

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

In April 2013, President ObamaâĂŹs FY2014 budget request called for a nation-wide reorganization of STEM efforts. Funds were removed from most government agencies and redirected to three agencies to consolidate these efforts: Department of Education (K-12 STEM), National Science Foundation (undergraduate and graduate STEM) and Smithsonian Institution (informal education). Whether or not this request becomes law depends on the government passing a FY14 budget that includes these plans. As a result, funding opportunities are rather uncertain at the present time. Below is a list of opportunities taken from the NSF website, with their notations regarding future due dates for proposals:

- Partnerships in Astronomy & Astrophysics Research and Education (PAARE) (NSF 13-566) Deadline Date: August 27, 2013
- Advancing Informal STEM Learning (AISL): Research on Learning in Formal and Informal Settings (NSF) Deadline Date: *being revised for 2014. No due dates currently available.*
- NSF Research Traineeship Program (NRT) (NSF) Deadline Date: *being revised for 2014, but is expected to be reissued as part of the nation-wide reorganization of STEM resources.*
- Research Experiences for Undergraduates (NSF 09-598) Full Proposal: Main due date each year: Fourth Wednesday in August, Annually Thereafter
- Innovative Technology Experiences for Students and Teachers (ITEST) (NSF 11-525) Posted: January 25, 2011

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 2013 Google awarded funding to 30 education partners across 18 countries. The application portal for the next cohort of award recipients will open in August 2013 for 2014 partnership.

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 Public Engagement program that funds a range of activities. These include a Small Awards Scheme 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 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 science communicators – generally seeking to reach a wide range of demographics and ages and across a range of science topics. The STFC also operates a Public Engagement 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 Public Engagement 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 and additional information can be found 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/

Several other funding bodies (e.g., the Nuffield Foundation, the Royal Society of Edinburgh, the Institute of Physics and the Royal Astronomical Society) can offer support to undergraduate projects of up to 10 weeks.

3.5 Essays on the Education and Public Outreach of the LSC

3.5.1 Multimedia and web-based outreach

Internet-based approaches play a central role in the LSC EPO program. Below we provide a brief summary of some elements of the diverse set of tools EPO experts use routinely.

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 expand the Spanish version mirror of the ligo.org web site, and to extend this translation effort to other languages. More details can be found in Chapter 6.

Many nice websites thrive that contribute to public outreach of the gravitational wave field, including the LLO educational website, the LIGO touring exhibit, the Einstein@Home screensaver, the "Einstein's Messengers" video, the Cardiff group, the AEI group, the Penn State group, the Caltech-Cornell Simulating Extreme Spacetimes, the MIT group with Scott Hughes, the LIGO social media, the independent blog of Amber Stuver, the Andreas Freise, the article, Who cares about physics today? A marketing strategy..., by Umberto Canella, and the Gravitational-wave Science in the High School Classroom by Farr, Schebert and Trouille.

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.

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

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.

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" [49], 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[2] (Enabling Virtual Organizations) [50] is a videoconferencing and desktop sharing system developed at the California Institute of Technology and now is in routine 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 [51] broadcast through the synergy 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

[2]EVO is being commercialised, it is not clear that its outreach efforts will continue.

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.

In July 2012, EVO was used to record and broadcast a series of lectures about gravity, General Relativity and LIGO, as part of a teacher professional development workshop at Sonoma [30] State University. Lecturers included Prof. Lynn Cominsky [30] (SSU) and Prof. Duncan Brown [35] (Syracuse U.).

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.

In 2012, the SSU [30] group has produced postcards that advertise Einstein@Home and its connection to the use of Fermi mission data to look for gamma-ray pulsars. If you would like to distribute these postcards, please email Lynn Cominsky at lynnc@universe.sonoma.edu, and indicate the quantity and postal mail address for shipping.

3.5.2 Citizen Science and Crowd Sourcing

3.5.3 Einstein@Home

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3.5.4 Schools and Conferences

Several Summer Schools and major conferences worldwide feature gravitational wave science topics and significant fraction of these are directly relevant for the EPO mission. A comprehensive up-to-date list of conferences with gravitational wave component can be found at the LSC Conference Webpage

From 2004 to 2012 the Center for Gravitational Wave Astronomy (CGWA) located at the University of Texas at Brownsville (UTB) hosted the Gravitational Wave Summer School at the university's facility on South Padre Island, Texas. The two-week introduction to gravitational wave astronomy was designed for graduate students and upper level undergrads, and topics covered typically included an introduction to general relativity, astrophysics of gravitational wave sources, detector instrumentation, and data analysis. Over eight years approximately 250 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 were provided for travel, accommodations and per diem expenses. The 8th and final Gravitational Wave Summer School took place May 28-June 8, 2012.

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 astronomy"), 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.

3.5.5 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 hard x-ray focusing Nuclear Spectroscopic Telescope Array (NuSTAR) mission, launched by NASA in June, 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.

- *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, multimedia 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

NuSTAR http://www.nustar.caltech.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. There are also iPhone apps that have been developed by the Fermi and Swift missions, which can be downloaded from iTunes. The Swift Explorer app notifies the user of gamma-ray bursts as they occur, and also has a gallery of UV and X-ray images. The Fermi Sky app is also available for the iPad.

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.

Similarly the award-winning Astronomical Society at the University of Birmingham has for the last four years run the very popular combination of popular science talks with night sky observation, called the "Patrick Moore Lecture Series, Tea, Talk and Telescope" These events regularly attract a large audiences, including many families and children of all ages.

3.5.6 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. During a second F2F meeting in March 2012 in Cambridge, MA., about 20 EPO group members met for a half day to assess progress since the previous year, and to forge plans for the future. 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 high

priority 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/.

   In the past year, the SSU group has produced LIGO and LSC stickers which have been distributed to LSC members as well as at various science festivals. If you would like to distribute these stickers, please send mail to Lynn Cominsky at lynnc@universe.sonoma.edu, and indicate the quantity and postal mail address for shipping.

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.

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.

It would be nice to develop an animated cartoon on the stile of Kip Thorne's animation at NASA's Space Place. The budget for this project is about $20k and would be appropriate for a supplemental to an existing grant. For more information contact: Marco Cavaglia [40]

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.

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 seminal EPO face-to-face 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.

4 Education and Public Outreach of the LIGO Laboratory

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 thirteen years of steady growth in the breadth of outreach activities and in the strength of regional partnerships, LIGO's site-based programs will reach nearly 25,000 people in 2013. 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.

4.0.7 Overview

Staff (4.25 FTE) are are responsible for operating the outreach programs at the detector sites. Numerous members of the site technical staffs and LSC technical visitors also participate in site-based outreach activities. The Hanford and Livingston outreach teams coordinate the outreach involvement of these individuals. The vast majority of Hanford and Livingston outreach contacts are face-to-face. Additional site-based interactions occur with visitors who connect to the sites via Skype and similar virtual platforms.

The LSC-EPO Working Group 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 detector sites.

4.0.8 LIGO Livingston Observatory and the LIGO Science Education Center

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 amplify 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 5924 K-12 school visitors with on-site ïňĄeld trips during the past academic year. The SEC trained 541 K-12 teachers and pre-service teachers through teacher workshops during the same time frame.

Since its inception, the SEC has seen an increase in LLO's on-site outreach attendance from 1100 on-site visitors in 2004 to over 10,000 on-site visitors during the past year. The SEC reached a total of 14810 contacts from July 2012-June 2013 (10,025 on-site, 4,785 off-site) through 210 programs and activities.

Needs and Future Plans

The SEC has transitioned to a regional collaboration headed by the Baton Rouge Area Foundation (BRAF), which 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.

From 2004 until 2010 the SEC saw a small but steady decline in teachers attending professional development opportunities with the SEC. Recently 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 the core audiences and ensuring that the longitudinal outreach efforts are effectively managed.

4.0.9 LIGO Hanford Observatory

Past and Current Activities

LIGO Hanford (LHO) hired a full-time outreach coordinator (EOC) in 2004 and this individual operates LHO's outreach program. The site offers 18 interactive exhibits to support school ïňĄeld trips and family-oriented outreach at the site. The EOC 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 2013 LHO will participate in approximately 12,500 outreach contacts, roughly 3900 of which will be visitors to the Observatory for school field trips, public tours and public events. The remainder will come from off-site interactions at schools, at school-based family events and at community exhibitions and festivals.

Needs and Future Plans

LHO continues to add pieces of Initial LIGO instrumentation for display in the public areas of the facility. In 2013, the site will continue to develop a self-guided tour for visitors that will utilize these displays. As the installation of Advanced LIGO proceeds, LHO's inventory of installation-related still photos and video footage continues to increase. Staff members must meet the challenge of editing and preparing portions of these materials for public consumption (primarily via the Web). Two LHO staff members serve as editors on the new LIGO magazine. Photos of site activities continue to be an important resource for the magazine. Washington currently serves as home to a pair of STEM-focused high schools (although more of these innovative schools are on the horizon). LIGO serves as a community partner for both of these schools - Delta High School in the Tri-Cities and Aviation High School near Seattle. A pair of students from each school will serve as interns at LHO during 2013.

LHO's current level of outreach activity has saturated the site's outreach FTE, a circumstance that could limit future growth of LHO's outreach program. Pairs of local undergraduate student assistants continue to come to the site for year-long experiences. A portion of these students' on-site time is directed to providing support for public outreach. The exhibit development, display development and event staffing that these students provide constitutes a key resource for outreach growth.

In 2013, LHO will host at least four high school students for volunteer internships at the site. The length of these experiences spans two weeks to twelve weeks. Internships such as these provide the students with work-based learning experiences that meet the spirit of new K-12 science and technology standards.

5 Formal Education

Traditionally, formal education is conducted in schools by classroom teachers, for students in grades K-12 and at Universities. EPO group work related to formal education includes the creation of standards-aligned and well-tested classroom materials, as well as training the teachers who will deliver these materials. It also includes direct work with students in classroom settings.

In the past significant formal learning about LIGO has been primarily focused on the communities local to the LIGO Observatories at Hanford, Washington and Livingston, Louisiana. In these locations, a few hundred teachers each year have been engaged in professional development opportunities offered by Observatory personnel. The first GW detections will provide an unprecedented opportunity to engage hundreds of thousands of students nation-wide in deeper learning by creating standards-aligned materials in the areas of waves and gravitation, and by training thousands of teachers nation-wide to use these materials in their classrooms.

5.1 Formal Education Unit Inspired by LIGO

The future discovery of gravitational waves will be big news - and teachers across the country will want to quickly understand the physics and astronomy behind these elusive phenomena. If we start now, we can be ready to answer questions from these teachers and their students - developing classroom ready, standards-aligned and well-tested materials that will be used when the demand is heightened by these greatly anticipated discoveries. The development cycle for these materials takes approximately three years, so it is critical that we start this process as soon as possible.

The recent report *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* by the National Resource Council's Committee on Conceptual Framework for the New K-12 Science Education Standards (2011) stresses that "The learning experiences provided for students should engage them with fundamental questions about the world and with how scientists have investigated and found answers to those questions. Throughout the K-12 grades, students should have the opportunity to carry out scientific investigations and engineering design projects related to the disciplinary core ideas." The *Framework* continues to specify Physical Science Content for grades 8-12 that includes gravitational fields and forces, as well as waves and their properties. These are common standards also found in the National Science Education Standards (from the National Science Teachers Association) and also in the AAAS Project 2061 Benchmarks. Although the relativistic formulation of the laws of gravitation that predict GWs is not included in any of these standards, we can use the excitement of LIGO science to create inspiring and engaging materials that do align with the standards, and that will be readily and eagerly used by classroom teachers.

The *Framework* also stresses the connection between scientific ideas and the engineering practices needed to conduct the scientific inquiry. For example LIGO instrumentation is a prime example of where an "Understanding of waves and their interactions with matter has been used to design

technologies and instruments that greatly extend the range of phenomena that can be investigated by science. The importance of the relationship between engineering practice and scientific data collection and analysis is also essential to ensure that students should learn how scientific knowledge is acquired and how scientific explanations are developed. Students should learn how science is utilized, in particular through the engineering design process, and they should come to appreciate both the distinctions and relationships between engineering, technology, and applications of science." Again, the development of LIGO technologies, including lasers, seismic isolation mechanisms, and optics, provides many excellent case studies illustrating these important points. These connections can and should be made in future materials developed by EPO.

5.2 Teacher Professional Development Related to LIGO

At the present time, both LIGO Observatories (Hanford and Livingston) conduct teacher professional development programs concentrated in their local service areas. LIGO Livingston Observatory (LLO) averages about 400-500 teacher contacts each year, while LIGO Hanford Observatory (LHO) averages about 170. Each laboratory reaches out to thousands of school children through tours, field trips and classroom visits. These numbers have steadily grown from a thousand students a year to over ten-thousand students a year - indicating an interest in LIGO related science and activities. However, there has been relatively little effort to date expended to create formal educational materials or long-duration teacher professional development programs that extend beyond the observatories' local areas. Funded by the US Department of Education through the Washington State office of the Superintendent of Public Instruction, LHO has worked within the southeast Washington Math Science Partnership (MSP) to train teachers from grades 3-8, offering annual two-week professional development institutes aimed at sharpening scientific inquiry skills. Key components of this program have been to develop mentor teachers to assist with LHO professional development (PD) and to provide coaching to new teachers as they prepare and implement their instructional improvement plans; they also disseminate inquiry learning strategies building- and district-wide. In addition, four teachers have interned at the LIGO Observatories each summer, performing research and developing plans, lessons and activities for incorporating part of their LIGO experience into their classroom instruction. LLO has similar, but different efforts taking place. MSP projects often use the lab as an extended field trip and learning opportunity, while two Louisiana Universities: Southern University Baton Rouge and Louisiana Tech conduct week to two-week long LIGO related professional development opportunities funded through the LA Board of Regents and the NSF as part of PHY 0917587. Recent external evaluation of the professional development conducted by LLO has concluded "The LIGO PD program is clearly highly regarded among its participants. In addition to high quality experiences and usefulness of the materials, teachers also reported strong learning gains in LIGO-related science concepts (waves, resonance, gravity). The success to date of LIGO professional development and the positive responses of teachers suggests that efforts should be made to expand the program's reach across the region and state and provide advanced or deeper leadership opportunities for teachers who have participated previously."

We encourage EPO groups to build on the existing professional development efforts pioneered by LLO and LHO in the local Louisiana and Washington regions by extending these opportunities to teachers nationwide who will be eager to learn about LIGO-related science and technology. One successful model (implemented at Sonoma State for NASA-funded programs) uses "Educator Ambassadors" - master teachers who can be trained by LIGO outreach personnel to train other teachers

to use LIGO-developed classroom materials. This "train the trainer" model has been a great success for NASA-sponsored high-energy astrophysics missions, in which bi-annual training of a cohort of 15-20 master teachers has resulted in over 63,500 teachers nation-wide learning (during the past ten years) how to use NASA-developed materials in their classrooms. In July 2012, the SSU groupâĂŹs training included a two-day mini-course on gravitation and LIGO. Materials from this course and selected EVO and other videos of the lectures are available for download here.

5.3 Partnerships with Existing Classroom Networks

We also encourage partnerships with existing networks that already have national reach into middle- and high-school classrooms. One example is the American Physical Society's Physics Quest project. Physics Quest experiments are performed by 13,000 middle school classrooms nationally, reaching over 350,000 students.

For students in high school, the Department of Energy and NSF-funded I2U2 project (Interactions in Understanding the Universe) offers the potential for true scientific inquiry. LIGO's I2U2 "e-Lab" offers a Web-based interface to LIGO seismometer data for students and teachers. Hundreds of students in Washington State and elsewhere in the U.S. have undertaken research tasks related to earthquakes and other forms of seismicity using the LIGO e-lab. In doing seismic research, students benefit from resources and support that the e-Lab Web site provides. However the I2U2 project is not very well known outside of the LIGO and Fermi-lab local areas. Teacher professional development opportunities and workshops about I2U2 at national, regional and state educator's conferences would greatly improve the reach and utilization of these excellent "e-Labs."

5.4 Formal Education Group Scope

Below is the comprehensive assessment of Formal Education Opportunities listing opportunities available for EPO members. As discussed in section 3.5.12 above, the current top priority for Formal Education is to develop new classroom materials that are standards-aligned, classroom tested and reviewed by experts, in order to engage students world-wide in the excitement of LIGO science and technology.

5.4.1 For Elementary School Students

Support & Involve Ages: 4 - 7

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Support & Involve Ages: 7 - 12

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

GW Picture Books

Instructable examples [52] are available from other fields:The Sonoma group [30] group has developed a pop-up book which illustrates active galaxies, and also includes a children's story. The Chandra Observatory has developed a coloring book.

Adapting famous books, such as Kip Thorne's "Black Holes and Time Warps, Einstein Outrageous Legacy", to the e-book and picture book format and for various age groups one might be able to re-purpose already successful best-sellers by fitting graphics style, pictures, and videos.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Curriculum Development

One example of how to engage elementary students in complex topics is to create stories that address literacy standards, and hands on activities that utilize mathematical standards. One example of this is the "`http://fermi.sonoma.edu/teachers/popup.php`" pop up book developed by the SSU E/PO group [30].

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

5.4.2 For Middle and High School Students

Activities, Demos, and Events

LSC members [21] participate in General Educational Development (GED) education programs (in Math and Science) that make a huge difference in the life of many students. These students often struggle to make time to study, but they are always enormously appreciative and motivated. They are also quite fascinated to have a window into the world of science, which LSC members can't resist telling them about. The traditional classroom model doesn't work well as new students come all the time and we have to use special circular curriculum that ensures that there is always something that can be taught for any given class. We also use the Khan Academy as an online supplement to the classroom as this website allows a coach to interact with their students to supervise the online learning process. This works well for people who need additional help. More involvement nationwide, expansion beyond Math, set-up of LSC tutor group for sharing experience are all inspiring possibilities for the future.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org` and `abbott@ligo.caltech.edu`.

Talks and Lectures

There are many classroom activities and demos that have been developed by Penn State [27] and other members of the LIGO project. They can be accessed from the `ligo.org site`.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Summer Programs

Many local summer programs [52] continue the formal education process. Examples include SSU's [30] `EXCEL program`, the `Lawrence Hall of Science summer camp`, and `Destination Science`.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Research Involvement

Authentic research experiences in classrooms are valuable for the students, and go beyond mere "inquiry" activities. Examples [52] of classroom use of telescopes include the `Microobservatory` and `Hands On Universe` projects. Sonoma State University also offers free telescope time to high-school

and college students through the Global Telescope Network (which includes both northern and southern telescopes).

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

"Office Hours" with LIGO Scientists

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Curriculum Development

Developing curriculum for the formal education system is a major undertaking, and requires years of iteration, testing and feedback from classroom teachers. This process also requires a knowledge of state and/or national standards, as well as the principles of instructional design. For examples [52] of well-regarded classroom materials, see the Great Explorations in Math and Science website and TERC.

Many standards-aligned and classroom tested educator's guides have been developed by the SSU E/PO group [30] that relate to LIGO objects of interest such as black holes, gamma-ray bursts and supernovae. The SSU group has also developed a series of activities that teach Newton's Laws. All these activities can be downloaded from the classroom materials sections of the Fermi and SWIFT web sites.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

5.4.3 For University Students

Promote and Support REU, SURF, Undergraduate Research

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Support Summer / Winter Schools and Rigorous Learning Events

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Colloquium and Seminar Organization, Placement, and Support

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Distribution of Video Recordings of Talks

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Web Materials

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Curriculum Development

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

5.4.4 For Educators

Promote Faculty Workshops

Professional societies such as the AAS offer faculty workshops regularly as activities that accompany the semi-annual society research conferences. For example [52], the CAPER team and the Center for Astronomy Education often provide these workshops which demonstrate effective pedagogical techniques for use in introductory astronomy courses. See the website for the CAE schedule.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Teacher Education Initiatives

Teachers typically attend professional development workshops organized either by their school districts, or by professional societies. The key professional societies in the USA are: the National Science Teachers Association, the National Council of Teachers of Mathematics, and the International Technology and Engineering Educators Association. In addition, many states have their own professional societies for science and math teachers. In order to provide professional development to teachers through one of these societies, one must either be a member of the society or partner with an existing member, and then submit a workshop proposal that will be reviewed before acceptance. Deadlines occur at various times during the year, but in general are about one year ahead of the time at which the meeting is held.

Teacher Training Workshops can be an effective way to indirectly reach many children through training teachers on how to to convey aspects of our field to their colleagues and their students.

Developing teacher training materials and making these directly available for the general public can further our reach and increase its efficiency and breath.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Organize Teacher Workshops

Organizing local or regional teacher workshops that do not tie into the national framework can be a considerable undertaking. Busy teachers do not have time to attend these types of workshops without some types of incentives. Examples include: a) workshop is free or provides a stipend for attendance b) free classroom materials or information not easily obtainable or understood are provided c) workshop is mandated by their school districts and/or d) workshop features a well known educator or PD-provider as the leader (for example, textbook author Paul Hewitt or Paul Doherty from the Exploratorium).

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Unified Teacher Materials Hub

There are many good repositories [52] of teachers' materials. Popular examples include the Teacher's Domain and the learning center at NSTA. NASA maintains a repository of classroom materials, called "NASA Wavelength".

An example of a compilation of faculty-friendly resources is the compendium of cosmology resources compiled by the Astronomical Society of the Pacific, for use in Astro 101 classes. Additionally Astronomy and cosmology research guides are also useful and available.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

5.4.5 For All

Support & Involve Ages: 18 - 23

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Support & Involve Ages: 23 - 35

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Support & Involve Ages: over 35

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Lectures/talks/festivals/expo

LSC hosted successful exhibitions at the USA Science and Engineering Festival in Washington DC, and at the World Science Festival in New York City. The `next USA SEF in DC` will be in April 2014. Additionally, the LIGO technology lends itself very well to exposure at `Maker's Faires`, which are now held in in the San Francisco Bay Area and New York. Representatives of the Columbia [12] group helped elementary school exhibitors at the New York Maker's Faire 2012 that was a nice success resulting in an invitation for next year's faire. "Mini-maker's faires" are also held locally and are oriented towards younger participants.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Create Open Source Educational Materials, Experiments, Applets

There are many repositories [52] of physics applets and educational materials, including the master catalog at `Compadre`, the multi-media resources at `MERLOT`, and the `National Science Digital Library`.

Other more limited collections include the "physlets" at the `University of Colorado` and the astronomy flash applications at the `University of Nebraska, Lincoln`.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Web Courses

A recent example [52] of an online teacher training course for multiwavelength electromagnetic spectrum lessons was recently sponsored by many different NASA missions. This course offered academic credit or continuing education credit through Sonoma State University [30], and can be `viewed on the web`.

The SSU [30] group is also developing an online course in cosmology for general education college students, contact `Lynn Cominsky` if you would like to have access during the testing phases. Other popular web courses for students (which do not offer credit) are available through iTunes university, the Khan academy, and new initiatives such as the `collaboration between Harvard, MIT and other universities`.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

5.4.6 Other

Facilitate Conferences

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Web Presence

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

6 inFormal Education

As is clear from the remainder of the white paper, there is a great deal of firmly established and highly successful informal education and public outreach activity already happening across the LSC. We have seen that these activities range in scope from local initiatives that engage LSC staff and students in delivering informal talks and workshops to astronomy societies and science festivals, through to coordinated global activities such as the "citizen science" program Einstein@Home. The EPO Group commends LSC members for their ongoing efforts across all of these informal education activities and encourages them to continue both delivering and reporting them in their MoU responses and future plans.

The purpose of this chapter is to highlight and summarise a number of specific informal education areas where significant additional effort by LSC groups would be welcomed – either to consolidate and strengthen current initiatives (several of which have already been described in detail in previous sections of the white paper) or in some cases to develop new avenues for informal education. In *all* cases the goal is to maximise the impact of our outreach activities, in terms of reaching a larger audience and exerting a positive influence on that audience's awareness of LIGO and gravitational wave science. By seeking to involve more LSC members and groups in these activities we also aim to make our outreach efforts more efficient, cost-effective and sustainable. Both of these broad aims – that of increasing the impact and sustainability of our outreach activities – would seem to be of particular strategic importance as we approach the commissioning and operation phase of Advanced LIGO and the onset of the "Detection Era" for gravitational-wave astronomy.

We have organised our informal education strategic priorities under the following headings:

1. Toys and goodies
2. Visual media
3. Audio media
4. Film, video animations
5. Interactive media
6. Print media
7. Performance art
8. Meet the Scientists
9. Expanding our audiences
10. Other

We invite LSC groups and individual members to identify from this list of informal education priorities activities to which they would be willing to contribute. The following sub-sections provide some further details about each of these priority areas. This list of priority areas need not be considered exhaustive, however, and the EPO group is always happy to receive ideas for other activities that do not fit neatly into the categories we have identified. Groups or individuals who would like to discuss any such ideas should contact `lsc-epo@ligo.org`.

6.1 EPO Informal Education and Outreach Group Scope

6.1.1 Toys and Goodies

Enabling people to create their own instruments [52] of education and outreach through advice, plans, ideas, and other open-source public documentation can allow us to reach and engage communities that are eager to create unique contributions to society.

Many instructable examples [52] from other fields, on how to help people create their own toys, t-shirts, coffee mugs and other items for personal use, can be found at `http://www.cafepress.com/` (see e.g., `Fermi satellite` and `SWIFT satellite`, or `Higgs boson t-shirts`) or similar sites where the interested public and team members can purchase items with their own personal funds.

T-Shirts

In recent years the EPO group has produced 'Black Hole Hunter' t-shirts which are quirky and eye-catching. If you have ideas for other t-shirt designs (using e.g. images or graphics from your own research) these would be very welcome. Designs could also be used for coffee mugs, mousemats, bookmarks etc.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Toys

Instructable examples [52] from other fields are `inflatable CMB beach ball` by NASA, `customized plushies of black holes and neutron stars`, and a `laser gadget from APS` that uses laser modulation to transmit your music across the dance floor.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Posters and Stickers

A high quality "beauty" poster of LIGO should be created that is suitable for distribution to the general public. Using some of the most beautiful images of LIGO hardware, set into a context of the entire Observatory, this could be very popular with classroom teachers, team members and the general public.

A variation on the basic poster would be to design a wall planner, customised with LSC images and information, suitable for distribution to e.g. high school science classrooms. Websites exist, such as `Create a Calendar`, that provide templates for this.

Stickers have now been created 10 to represent both LIGO and the LSC.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Origami

Instructable examples [52] include creations from Jocelyn Read [15] and paper models of NASA satellites that are commonly created to raise public awareness of the technology of the detectors and spacecraft, such as the `Fermi satellite` and `Hubble Space Telescope`.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

LEGOs

Instructable examples [52] from a other fields are the `LEGO models of NASA rovers`. LEGO models of satellites have been `created and are sold by commercial entities`, and are very popular.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

6.1.2 Visual Media

As we approach the era of first detections it will be increasingly important wherever possible to establish relationships with professional media organisations such as PBS, Nova, the Discovery Channel, NPR, the BBC etc. We want the LSC to be in a strong position to pitch programming ideas to these organisations both in the run-up to, and during, the first Advanced LIGO and Advanced Virgo science runs, to build awareness of the anticipated breakthroughs in gravitational wave astronomy that will follow, and of course after the first detections have occurred.

While the building of these media relations and formal planning for media coverage of the first detections is a core responsibility of the LIGO directorate and Executive, the EPO group welcomes any ideas and proposals for future programming as well as informal efforts by LSC members and groups to establish links with the media in their location, from which more formal collaborations might grow naturally in the future.

Comics

Comics are a great and proven way to reach a broad segment of the society and all ages. The rich research and social life of the collaboration provides the perfect opportunity to develop comics that engage the public and follow our life, challenges, and discoveries. Instructable examples [52] from a other fields are the `PhD Comics.com`, the `HowToons.com`, the `Comics from APS`, the `Dark matters`, and the `Higgs Boson Explained`.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Cartoons

Cartoons can captivate broad audiences while clearly explaining complex ideas. They can be an extremely effective tool to for example teach our science and technology to the public. Instructable examples [52] from a other fields are `The Higgs Boson - A Tales from the Road Comic` and `The Story of Stuff`.

The Space Science Education and Public Outreach group at Sonoma State University [30] featured LSC related stories in two of their *"Epo's Chronicles"* episodes. The English versions of episodes `116` and `117` also contain links to their Italian, Spanish and French versions.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

"Art, Beauty, Science" Project

As the success of the LIGO exhibitions at the World Science Festival and USA Science and Engineering Expos shows, art can be a powerful ally in conveying our science and excitement. This project intends to reach and engage the public through all kinds of art about astrophysics.

For example contests could be held for students of all ages to create art relating to LIGO. One example [52] is sponsored by IGES for students in grades 2-4. This contest has been held annually since 1996.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Graphic Design

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Visual Material Development: 3D Models, Animations, and others

Many animations have been created to accompany NASA projects. For example [52], NASA Goddard Space Flight Center's Scientific Visualization Studio has a searchable website of material that covers topics in astrophysics, earth science, remote sensing and planetary science. Building up a library of similar videos to illustrate gravitational wave phenomena would be very valuable.

Already there are some excellent examples within our community, most notably the 'virtual tour' of the LIGO observatory developed by the LSC group at the Eotvos University in Hungary. However there is tremendous potential for expansion, and for taking the virtual reality to the next level – commensurate with LIGO's status as absolutely at the cutting-edge of science and technology. Possibilities include:

- Developing a full 3-D virtual tour animation that allows the user to 'walk' around the LIGO sites at his/her own pace,
- Making the animated material fully zoomable and clickable with additional background content on LIGO science and engineering,
- Developing augmented content to enhance an on-site tour, via e.g. an app or (in the longer term) a heads-up display such as google glass.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Manga

Manga has major impact on the younger generation and it is also promoted by educators. Manga science is popular and the LSC has great manga base material. Instructable examples [52] from a other fields are Manga Guide to the Universe and Manga Guide to Relativity. Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Slideshows

College teachers may need slide sets and lesson plans that can be used and/or adapted for beginning astronomy and physics classes. One example [52], that has been developed for planetary science is available here.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

6.1.3 Audio Media

“Sounds of Gravity” Project’

The cosmos can provide us with a wide variety of phenomena that be experienced directly, or represented, as sounds. Publishing predicted waveforms as audio files in an attractive package can be a productive and constructive way to engage people, and is a core feature of the `Black Hole Hunter` game described elsewhere in the white paper.

LIGO has some sounds of characteristic waves on the ligo.org site. However, considering the vast array of numerical simulations, more audio sounds could be generated. Engagement of this nature in the broader astrophysics community has been highly successful, for example [52]: `sets a gamma-ray burst to sound` and the “`heartbeat`” of the smallest black hole discovered by RXTE is a unique treat.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Development of Materials for Audio Media / Radio

Radio and podcasts are powerful tools in conveying science. Having ideas on hand, good speakers standing by, and sound bites ready can greatly enhance the high profile radio show of the future. Failing to plan is planning to fail here.

Instructable examples [52] from other fields are `http://sciencefriday.com/` and `http://www.nature.com/nature/podcast/`. LSC members could also sign up as a `Global Science Advisor` for the Earth and Sky show.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Creative Musical Projects

For the launch of NASA’s GLAST satellite, composer `Nolan Gasser` created the “`GLAST Prelude`”. Later, Gasser composed the “Cosmic Reflection Symphony” which was accompanied by a narrated script, and a video. The symphony debuted at the Kennedy Center in Washington DC in 2009.

The highly successful `Einstein’s Cosmic Messengers` multimedia concert, conceived by renowned musician and composer Andrea Centazzo and LSC member Michele Vallisneri, provides another effective template for creative musical projects and performances.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Development of Web/PodCasts

In addition to video content, there are good opportunities for high impact outreach via audio podcasts and WebCasts. The EPO group can help with ideas and strategies for content, web hosting and dissemination.

An excellent example [52] of a community wide webcast/podcast project is the `365 Days of Astronomy`, in which various scientists and groups contributed podcasts on various astronomical topics that featured new content each day. It was originally aimed to cover the International Year of Astronomy in 2009, but it was continued.

Another excellent example from within our community is the `Science Face project`, which features a series of short interviews with world-leading scientists working the fields of gravitational astrophysics and relativity. This very successful project has been running for several years and the website will shortly be relaunched, with enhanced content and additional interviews.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Promoting Radio Placement of our Field

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

6.1.4 Film, Video, Animations

Development of Materials for Professional Broadcast & Documentary Media

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Promoting Film(Hollywood) Placement of our Field

In-movie placement of true science or positive scientist characters can arise curiosity and lead people to scientific engagement and increase general knowledge levels. It can be a powerful tool.

Instructable examples [52] from other fields are The Mighty Thor and Hollywood Contagion.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Development of Educational Videos for Web Publication

The EPO group also encourages development of more 'home grown' video and multimedia content, appropriate for dissemination via YouTube and our social media platforms, and building on excellent existing examples such as http://www.einsteinsmessengers.org/. Particularly welcome would be content that showcases LIGO staff and students, helping to lend a human face to the collaboration (see also the excellent http://www.scienceface.org) and highlighting the challenges of constructing and commissioning the 2nd generation detectors.

Perhaps straddling the boundary between 'home grown' educational videos for web publication and development of materials for professional broadcast is the opportunities offered by a organising a TEDx: an independently organised TED event. These events can achieve extremely high profile and impact and are becoming increasingly common in other fields of science.

The EPO group wishes to identify, as a top priority for 2013-14, the organisation of a high profile TEDx event that will showcase gravitational wave science as a frontier subject that excites, inspires and challenges the public and seeks to answer fundamental questions about the nature of our Universe. The theme of the TEDx may be broader than *just* gravitational wave science, although we would seek to ensure that our field enjoys a prominent role within it.

Plans for the proposed TEDx are at a very provisional stage, although Columbia University has been identified as a possible host. Any LSC members or groups interested in developing the plans for a TEDx, and bringing them to fruition during 2013-14, should contact lsc-epo@ligo.org as soon as possible.

The Eotvos University group has put together a useful summary and guide to the most popular science education and video sites. The document can be found on the DCC.

6.1.5 Interactive Media

Develop and Promote Games

Over the past few years several LSC groups have successfully developed online games that aim to present and explain gravitational wave science in an engaging, fun and highly interactive manner.

These games – most notably the UK Cardiff group's "Black Hole Hunter" and Birmingham group's "Spacetime Quest" have great potential for both formal and informal education. Building on these successful projects, the EPO group would particularly welcome:

- ideas for developing new online game content,
- offers to help develop app versions of new or existing games.

In 2010 the gravitational wave group at the University of Birmingham created a new and unique online platform (www.gwoptics.org) to provide and distribute information, media and software tools for teaching and public outreach related to gravitational waves. The idea is to provide in one place fun activities, information about GW science and access to the real software tools that are used for designing GW detectors. This initiative is described in detail in Chapter 10. The items found on www.gwoptics.org include:

"Black Hole Pong" is an arcade-style game, a re-edition of the classical game Pong, with black holes and stars in place of paddles and a ball.

GW Ebook: A short selection of texts written by students introducing gravitational waves and the various topics of GW detector design.

Finesse and Simtools: One step away from the games and simple interactive simulations is Finesse, see Freise et al "Frequency-domain interferometer simulation with higher-order spatial modes" CQG 21 (2004), one of the main interferometer simulations in the field.

Additional interactive games with topics related to LIGO include the Alien Bandstand, Live from 2-Alpha and Solar Supernova, and Space Mysteries.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Expansion to Multiple Platforms: iPhone apps, Android apps

Instructable examples [52] from a other fields include the LHC Android App.

Astronomy apps such as Google Sky are extremely popular, and the creation of related content for the 'gravitational wave sky' – e.g. featuring information about extereme atrophysical objects and possible sources of gravitational waves – could harness some of that existing market.

Any LSC members interested in contributing (or indeed leading) the production of a regular newsletter should contact lsc-epo@ligo.org.

Development of Augmented and Virtual Reality

The design and construction of the LIGO Observatories has made extensive use of state-of-the-art software for computer aided design and 3-D visualization. The experience and expertise that resides within the LSC in this area offers significant opportunities for outreach and informal education in two particular respects:

- Providing design and visualization tools that could be directly applicable in other fields of science and engineering,

- Generating high-resolution visualizations of the Advanced LIGO detectors, with the potential for their use in e.g. interactive 'heads up' virtual reality displays such as google glass. These visualizations could be disseminated directly via the LIGO website or could form the basis for multimedia resources that will be made available to the broadcast media when the Advanced detectors become fully operational, as part of our media strategy for the detection era.

Developing, Organizing, and Providing Exhibitions

As detailed elsewhere in this and earlier white papers, the EPO group has led the design, delivery and display of two NSF-funded exhibits, entitled 'Astronomy's New Messengers' showcasing gravitational wave science – with similar, smaller exhibitions also having been successfully displayed at various events elsewhere around the world. A detailed overview of the design, development, specification and display history of 'Astronomy's New Messengers' can be found in Chapter 10.

While we hope to continue to display these exhibits wherever it is practical to do so, there are significant logistical hurdles to their deployment in terms of cost, space and manpower.

We believe there remains an excellent case for developing a more streamlined exhibit, essentially in 'kit' form, that could be available for deployment by any LSC group (at least in the US, in the first instance) and could be easily transported or delivered from one host venue to the next, with minimal effort required for assembly and maintenance. Elements which the exhibit 'kit' might contain include:

A pop-up LIGO banner an example hi-res image of which is now available on the EPO wiki,

A portable backdrop on gravitational-wave astronomy (an example hi-res image of which is now available on the EPO wiki,

A small table-top Michelson interferometer,

Multimedia items: movies and animations on gravitational-wave astronomy (see existing items on the EPO wiki for examples),

Computer displays or touch screens for showing multimedia and/or running games software, such as Black Hole Hunter. If these can be fully interactive, e.g. involving X-box or Wii controllers, they will likely appeal more strongly to older kids.

A supply of handouts about LIGO science and technology, including copies of the science summaries now routinely being produced to accompany new LSC publications,

Games and puzzles (e.g. mazes, crosswords, word searches) suitable for younger kids. Several examples now exist on the EPO wiki but a wider range would be useful – e.g. 'dot to dot' or 'spot the difference' puzzles, or simple line drawings for younger visitors to color,

Simple 'hands-on' activities suitable for younger kids, to convey basic concepts about gravitational waves and spacetime – such as a slinky to demonstrate fundamental wave properties and a stretched rubber or lycra sheet to allow a simple demonstration of spacetime curvature.

LSC members and/or groups interested in helping to develop this exhibit kit should contact lsc-epo@ligo.org.

Science Museums and Planetariums

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

6.1.6 Print Media

As a natural companion to the previous sub-section, it is also very important that we strengthen the collaboration's links and relationships with the printed media, newspapers and magazines. The EPO group welcomes suggestions for media stories from across the LSC and we encourage LSC members to identify and take up any opportunities they have to build contacts with science and mainstream journalists in their locales – e.g. by inviting them to visit your institution and tour your labs, or briefing them on recent science stories relevant to gravitational wave science. Bear in mind that local news organisations may be more willing to cover science stories that have a strong local connection and/or human interest angle. The EPO group can offer help and advice with generating and placing such stories in the printed media. In addition, most if not all LSC institutions will have experienced staff working in their institution's press office who can also help.

Development of Brochures and Leaflets

As a useful adjoint to our growing archive of science summaries and other similar resources that can already be found on the EPO wiki, we encourage the design of more generic leaflets and brochures showcasing LIGO science and technology. Offers from groups willing to invest in professional graphics design and production are particularly welcome as these will likely have greater impact. Many internet based suppliers can produce professional-looking materials (pop-up banners, flyers, handouts, brochures etc) at very competitive prices – a list of useful websites will be maintained on the EPO wiki to help groups locate good suppliers. The EPO group can advise and assist with content, writing style and layout, but a good general principle is to design content that is adaptable to a wide audience – from informal casual learners to professional educators, policy makers and politicians. High quality images suitable for inclusion in such resources can be obtained from e.g. the Advanced LIGO project archive maintained by the LIGO laboratory. For more information about this contact lsc-epo@ligo.org.

Promoting In-Fiction Placement of our Field

In-fiction placement of true science can arise curiosity and lead people to scientific engagement and increase general knowledge levels. It can be a powerful tool.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Material Development for Printed Media, Newspapers, Magazines, and Others

Instructable example [52] on books that can reach a diverse set of learners from a other fields is a pop-up book from ATLAS and LHC. Similarly, a pop-up book illustrating LIGO would be another way to reach a similar target audience.

Noreen Grice has pioneered the use of tactile books for visually impaired learners that allows users to feel the outlines of different space objects, telescopes and phenomena. A similar book illustrating the parts and science of LIGO would be a great addition to the collection and significant value for the readers.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Catalyzing Science Summaries

A significant recent EPO activity has been the creation of an online 'Science Summary' webpage, aimed at the level of a scientifically literate non-specialist, to accompany new LSC publications. Stand-alone hardcopy versions of these science summaries are also being produced and archived on the wiki, for distribution at e.g. science fairs and other outreach events.

During 2012-13, the EPO group has helped edit more "public friendly" Science Summaries of LSC publications. As of June 2013, there are 17 completed summaries, all of which exist in both online and pdf 'flyer' formats.

LSC groups should consider contributing to the production, editing and especially the dissemination of these science summaries. In particular we welcome suggestions for new ways (e.g. via email lists, arxiv.org, http://astrobites.com, web fora or other online communities) for advertising and distributing these summaries to help maximise their impact.

Any LSC members interested in contributing to the production, editing and dissemination of the science summaries should contact lsc-epo@ligo.org.

Publishing LSC Newsletter and Magazine

Many scientific collaborations and organisations (e.g. CERN, LSST and various NASA projects) produce a regular newsletter, usually in electronic form which facilitates wide circulation at minimal cost. The real cost of producing such a newsletter is in staff time and effort; however the benefits of a regular newsletter in terms of wider impact could be substantial.

The LSC has started a regular publication in 2012, the 'LIGO Magazine', with Andreas Freise [6] as Editor in Chief. While the main aim of the magazine is to enhance the communication within the LSC itself, the quality of the content and production have been carefully chosen such that the result will be suitable for several kinds of public engagement and outreach.

The EPO group has been considering setting up a LIGO newsletter. Key challenges to doing so are:

- identifying an editorial team
- generating and editing content on a regular basis
- disseminating the newsletter as widely as possible

Any LSC members interested in contributing (or indeed leading) the production of a regular newsletter should contact lsc-epo@ligo.org.

6.1.7 Performance Art

"Einstein's Cosmic Messengers" Solo Performance

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

"Astrophysics and Dance"

Instructable examples [52] from a other fields that are experimenting with dance in outreach: the Dance Your Phd, the , and the .

The innovative dance performance The Matter of Origins directed by Liz Lerman explores the origins of matter and the mind's capacity to understand beginnings from the quantum to the cosmic scales.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Spoken Word

Instructable examples [52] from a other fields include the video on Celebrities stating the need for Science.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

6.1.8 Up Close and Personal: Meet the Scientists

Interviews with LSC Scientists

When reaching out to people, the human and personal connection is vital. Providing high quality video and/or audio interviews with LSC scientists, covering their goals, motivations, and daily life while conveying excitement can result in scientific career choices. Instructable examples [52] from a other fields are Face to face with the people who make science happen, This is my job (PM), AIP Oral History Project, and Science Magazine.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

"Travels of an Astrophysicist" Project

The LSC has a global reach, global instrumentation, and global culture, while maintaining tremendous diversity on every way. As National Geographic Magazine(TM) is a word favourite for generations, short movies, photo galleries, and interviews reflecting the geographical, cultural, and style varieties within the team that seamlessly works together for the common scientific goal can be exciting for many. Instructable examples [52] from a other fields are http://www.nationalgeographic.com/. Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Blogs By LSC Scientists

The most widely read LSC scientist blog is Living LIGO [52] by Amber Stuver [23], from LLO. Although it is not an official LIGO publication, it offers clear explanations [52] of questions of interest to the LIGO-attentive public, as well as personalizing the LIGO project. See also the subsection below on 'Explanding our audience' for more details.

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

Guided Tours

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

6.1.9 Expanding Our Audience

Engaging through Social Media: Facebook, Twitter, and Others

Recently the EPO group has been seeking to grow LSC activity in the area of social media. This can help us to significantly increase the impact and geographical spread of our outreach, widen its

demographic coverage and help to build an audience of followers as we approach the era of first detections.

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 [53]. A strong connection is one in which an individual has repeated contact and interaction with another 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 [54]

Any LSC members or groups interested in helping with these social media efforts, should contact lsc-epo@ligo.org. We now describe our existing efforts in more detail.

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 in March 2011 Twitter stated that each week the site sent 1 billion messages [55]. 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 [56]. 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.' [57].

We have set up a generic LIGO twitter account, @ligo, and recruited a small subgroup of LSC members who have access to it. Through this group we seek to maintain a steady stream of tweets on topics relevant to gravitational wave science. An email has been sent to lsc-all explaining the procedure for contributing tweets. We encourage LSC members to consider getting involved in supporting our twitter acount – either by recommending stories or indeed volunteering to join the subgroup of tweeters. @ligo currently (4/6/13) has 1287 followers – an increase of about 50% since spring 2012. However, we have a long way to go: @CERN has more than half a million followers, for example. Tweets are posted to this account at the rate of about one to two per day and contain news and

information from the collaboration as well as science-related highlights from outside the LSC.

In 2012, EPO started a "ticketing" system for generating tweets as a uniform community. All members of the LSC are invited to submit material through this system, and the social media watch team of the EPO group members will choose the proper format and venue for the submissions in order to generate the most fitting new item.

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 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 [58] and a world map of social networks shows that Facebook has by far the largest international reach of a single vendor/application [59].

A generic LIGO facebook account, known as the LIGO Scientific Collaboration, has also been set up, with similar aims to that of our twitter account. If you are an LSC member with an active presence on facebook, please consider 'friending' LIGO and thus potentially introducing us to your own facebook friends. If you have any news stories that you think we should be covering on facebook, please email them to lsc-epo@ligo.org.

The LIGO outreach user name on Facebook 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 (June 2013), we are 'friends' with 410 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.

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.

Personal Blogs

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. 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 [60]). 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[61]. This story was then picked up by multiple internet outlets including Discover Magazine's *Cosmic Variance* blog [62] and the The Discovery Channel's news site [63]. *N.B. Approval from the LSC Spokesperson and the P&P Committee was attained before this story was published therefore it is classified as unreviewed. Here is the official release.*

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

'Blog squad'
As well as maintaining our own blog presence on the web, the EPO group periodically monitors other blog traffic looking out for stories or comments relevant to gravitational wave science – particularly those which are overtly critical towards our field. While some such blog comments emanate from 'fringe' sources which are not worth engaging with, others are from more respectable sources and/or feature questions that are motivated by genuine scientific curiosity but may belie some fundamental misunderstanding. Responding to these bloggers can be worthwhile, clearing up misconceptions and spreading positive attitudes to LIGO science. The EPO group would welcome the help of more LSC members to assist our 'blog squad' with this activity.

The EPO group also receives occasional notifications from the collaboration when a blog inaccurately portrays the science being conducted by the collaboration. 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.

Multilingual Efforts: Web, Translations, Foreign Tweets, and Others

The LSC generates a wide range of online and hardcopy resources that are suitable for the wider public and informal education purposes; these include a number of existing resources and several more that are proposed in this white paper to be developed in the near future. An EPO priority is to provide translations of these resources, particularly into Spanish and Chinese (although other languages would also be useful). LSC groups are encouraged to contribute to the effort.

Some EPO resources may also benefit from national or local 'tweaks' to highlight areas of particular relevance (e.g. alignment with national/local specific school science curricula or highlighting of contributions from national/local LSC groups or individuals).

This effort can be an example of beneficial collaborations between departments in a University as humanities departments can be of significant help when translating and communicating our research to foreign cultures.

A good example is the Balearic Islands Relativity Group that has been working on increasing the gravitational waves outreach `resources available in Spanish`.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Interfacing to LSC Diversity Group

To ensured the highest efficiency, close connections to the diversity group of the LSC is a must.

Any LSC members or groups interested in helping with this effort, should contact `lsc-diversity@ligo.org`.

Recruitment

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

New Websites

There is an internet"renaissance" for educational websites that engage the public. Interfacing with successful endeavours and learning from their great examples when developing them for the LSC is a great strategy. Instructable examples [52] of fun science education web and video sites [1]:

`Vsauce`, `Minute Physics`, `Sci Show`, `Crash Course!`, `C.G.P. Grey`, `Vihart`, `Numberphile`, `TED Ed - Lessons worth sharing`, `TED Ed - Lessons worth sharing`, `Periodic Videos`, `Idea Channel`, `Idea Channel`, `Smarter every day`, `Veritasium`, `Soul Pancake`, `Soul Pancake`, `NurdRage`, `THNKR - Change your mind`, `THNKR - Change your mind`, `The Brain Scoop`, `Green Power Science`, `DeepSkyVideos`, `Sixty Symbols`, `The Spangler Effect`, `Bigthink`, `James May's Q&A`, `Knowledge Badger`, `Numb3r hub`, `Live experiments`, `Global Squeeze`, `Mind Warp - Sector Four`, `Labisodes`, `Sulifizika (in Hungarian)`.

Any LSC members or groups interested in helping with this effort, should contact `lsc-epo@ligo.org`.

Massive Open Online Courses

Massive Open Online Course (MOOC) is becoming mainstream. Instructable examples [52] of online science course sites [2]:

[1] collected by the Eötvös University [14] team
[2] collected by the Eötvös University [14] team

edX, OpenCourseWare, OpenCourseWare, Coursera, KhanAcademy, TED, Open Yale Courses, Stanford Engineering Everywhere (mainly Programming courses), Get More From Life (a weblog by Scott Young) , Get More From Life (a weblog by Scott Young) .

Any LSC members or groups interested in helping with this effort, should contact lsc-epo@ligo.org.

6.1.10 Other

"Engaging Young Minds" Project

Early and playful engagement of children in science is extremely important and beneficial for the broader society on the long term. This is the goal of the "Engaging Young Minds" Project.

>From our experiences displaying 'Astronomy's New Messengers', it would be very useful to have more handouts and activities particularly aimed at younger visitors. This is an area where e.g. NASA outreach is especially effective but provides some good examples that can easily be adapted to gravitational wave themes, including:

- line drawings suitable for coloring in
- join-the-dots and 'spot the difference' puzzles
- word searches, anagrams and crosswords
- quizzes and 'amazing facts' sheets

Another possibility, although one requiring considerably more effort, is the production of a LIGO comic aimed at younger children. This could be produced regularly (e.g. every few months) as an ongoing feature – perhaps starring our own LIGO characters – or as a one-off outreach effort.

Any LSC members or groups interested in helping with the production of a LIGO comic, or other resources aimed at younger children, should contact lsc-epo@ligo.org.

7 Professional Outreach

7.1 EPO Professional Outreach Initiative Scope

7.1.1 Internal Education

Teach LIGO to LSC members and Other Professionals

Teach the Art of Funding

Outreach Abstracts

Teach Effective Communication

Interface to LSC entities: WebCom, P&P, LAAC, and Others

Dictionary & Handbook Project

7.1.2 For Broader Scientific Community

APS, AAS, AAAS, IEEE, OSA, and others

Facilitate Employment, Recruitments, and Conferences

Professional Tutorials through Web, Radio, WebCasts, PodCasts

GWIC

Software Tools

Birmingham maintains and provides the interferometer simulation software package Finesse. Finesse is one of the main simulation tools used for GW detector design and commissioning. However, it has been conceived as a general purpose tool and provides an easy access to simple laser optics examples. For example, it is commonly used for simple *numerical experiments*: the software takes only a few minutes to install and a first simple interferometer, such as a Michelson or a Fabry-Perot interferometer can be setup equally fast; students can then learn by playing with the setting of these optical setups. The simulation is ideally suited for an iterative and playful approach because a typical simulation run for a simple example only lasts milliseconds. Therefore the simulation not only represents a crucial tool for the detector development, it also serves as a outreach and teaching platform.

Finesse has been used to enhance optics lectures for university undergraduates and can also be used to support class room activities in other situations. The software comes with simple simulation examples and an extensive manual providing an overview of the mathematical models and pointers

to optics background material. Finesse examples are also provided as part of the open access review article on "Interferometer Techniques for Gravitational-Wave Detection".

Further, Finesse is provided as open source, with a transparent and professional online software management system. Like the elogs of the detector, this allows members of the public to follow or engage with the development of the software in real time and provides a direct view into the work of GW scientists.

7.1.3 For Amateur Scientists

Distribution of Environmental Data; Enable Access and Use

Engage, Excite, and Facilitate Amateur and Citizen Science

Facilitate Crowd Sourcing

7.1.4 For General Public

Printed/Broadcast Media

Highlight Spinoff Tech

Development of Professional Exhibits

7.1.5 Other

Enable and Facilitate Industrial and Corporate Relations

Facilitate/Provide Science Interpretation for Policy Making

8 Ongoing Projects, Plans, and Commitments

8.1 EPO Committee and Coordination Scope:

8.1.1 MoU Review, Reporting, Coordination

8.1.2 Press/Media Relations

8.1.3 White Paper Editions

8.1.4 Compilation of Statistics, Efficacy, Performance Measures

8.1.5 Award, Prize, Fellowship Surveys and Highlights

8.1.6 R&D on Effective Communication

8.1.7 R&D on EPO and Outreach Innovation

Cominsky will work with the LLO and LHO outreach staff and the E/PO group to develop new outreach opportunities [BSH] [30].

8.1.8 GW History Project

8.1.9 Formal Education Group

Cominsky will continue to pursue opportunities to gain funding to support Formal Education efforts on behalf of LIGO. [30].

The current top priority for Formal Education for middle and high schools is to develop new classroom materials that are standards-aligned, classroom tested and reviewed by experts. Our top priority for college students is to create lower division resources that can be used in community colleges to train faculty and engage students in the excitement of LIGO science and technology, with a special focus on reaching under-represented populations.

8.1.10 Informal Education Group

Hendry [17] and colleagues will continue to pursue opportunities to broaden the scope and impact of our informal education activities, and strengthen their sustainability. Particular focus for the coming year will be to:

- build our network of social media followers, and increase the range of content that we present via social media platforms, and the frequency with which we do so

- maintain our output of high-quality science summaries to accompany LSC and L-V publications, and seek to disseminate these as widely as possible
- develop a streamlined and sustainable ”exhibit kit” that can be easily shared across the collaboration and thus deployed regularly at outreach events and science festivals

8.1.11 Professional Outreach Group

Kalogera will continue to work towards strengthening the connections and interactions between the LSC and the astronomy and astrophysics community whenever opportunities arise. [26]

The current top internal priority in professional outreach is to teach various critical aspects of Advanced LIGO to the LSC communities engaged in other critical aspects of the project and to develop the related educational materials for future use.

8.1.12 National and International Partnerships

8.2 Formal Education Group Scope

8.2.1 For Elementary School Students

Support & Involve Ages: 4 - 7

Support & Involve Ages: 7 - 12

LSC members will be making efforts to involve children in this age group through exposure both in and out of schools. Members of Trinity will continue giving talks on LIGO and gravitational waves for San Antonio elementary school students, Smith will continue to host students at CSU Fullerton for tours of his gravitational-wave labs, and Rodriguez will volunteer as a mentor for the Boys and Girls club of Chicago [15, 26, 36].

GW Picture Books

Curriculum Development

Members at University of Western Australia plan to experiment with the narative approach to learning in primary schools. The idea is that the concepts of general relativity can be easily assimilated by young people who have not yet been indoctrinated with Euclidean geometry, an idea that has been, and will continue to be, tested with a full scale classroom physics program on general relativity and non-Euclidean geometry for 11-year-olds. There is also a plan to develop, along these lines, a pilot program of quantum mechanics for primary students and test whether quantum concepts can be understood by young children. This “Science Education Enrichment Project” aims to evaluate the benefits of this type of education in realtion to changing student attitudes to the maths and sciences [46].

The Glasgow group has been working to reshape the formal education material developed for the physics “Curriculum for Excellence” syllabus in Scotland, and plan to include YouTube videos and podcast content as part of that curriculum [17].

8.2.2 For Middle and High School Students

Activities, Demos, and Events

Groups will continue to organize and hold events for high school students, including running a weekly astronomy club meeting [45], receiving high school students on campus where they can participate in events such as the “Playing at Being Einstein” program which includes a documentary on gravitational waves as well as educational games [5], receiving high school students on campus for lab tours [15], and organizing public events in general [20].

Talks and Lectures

LSC members from various groups are committed to continue giving talks and presentations about LIGO research at local high schools [5, 36, 43]. Gustafson will collaborate with a local high school teacher to run a series of montly “Talk with a Scientist” sessions, targeted at interested high school students in the LIGO Hanford area [39].

Summer Programs

The CGWA will organize the XXI Century Ambassadors program, an introduction to astronomy program for local high school students [43].

The 9th Astronomy Ambassadors Academy at UTB will take place June 10-27, 2013. High school students will receive training in data analysis techniques applied to gravitational wave astronomy and radio astronomy. The students will work on a research project related to the search for pulsars at the Arecibo Remote Command Center (ARCC) located on the UTB/TSC campus and gain experience with electronic instrumentation and computer programming used for the Low Frequency All Sky Monitor (LoFASM) which is being constructed by UTB. Students will also visit the McDonald Observatory in the Davis Mountains of west Texas as part of the program [43].

The second REU/RET program will take place from June 3-August 9 at UTB. Twelve students (8 from outside UTB and 4 UTB students) and three local teachers will participate in the program. At least 7 of the projects will involve gravitational wave astronomy, and 3 or 4 students will visit LHO during the program. We received 176 applications for this yearâĂŹs REU [43].

Research Involvement

A new initiative to involve 8th and 9th grade students in transient astronomy research, using robotic telescopes, will be undertaken at University of Western Australia [46]. Riles will continue to mentor local high school students in LSC research [39], and and yearlong science projects in LIGO topics for teams of science/math teachers and 2-3 high school students will be facilitated at Loranger High School [33].

“Office Hours” with LIGO Scientists

Christensen will develop a method whereby LIGO Scientists can use EVO to connect with high school classrooms. He will establish a program where LIGO scientists can hold “office hours”, during which high school students and teachers can connect and ask questions. Presentations to classrooms via EVO can also be scheduled [7].

Curriculum Development

Ballmer and Brown will continue to support Syracuse University Project Advance, which allows high school students to take classes at Syracuse University, and the Say Yes to Education Syracuse project [35]. Farr will continue implementing lessons based on LIGO and gravitational-wave astronomy in local high school classrooms, and the Glasgow group will continue reforming the Scotland physics curriculum [17, 26].

8.2.3 For University Students

Promote and Support REU, SURF, Undergraduate Research

The IREU program at University of Florida is funded until 2015 and will send between 14 and 16 US undergraduate students to international collaborators for summer research experience. Other groups such as `UTBrownsville` and LSU will continue hosting undergraduate students in the REU program, and Gustafson will assist in mentoring SURF projects [24, 39, 43]. Outside of these programs, members of University of Oregon will continue to provide research opportunities for undergraduate students on LIGO topics [41].

Support Summer / Winter Schools and Rigorous Learning Events

Members of the University of Balearc Islands will give lectures on gravitational wave astronomy ata graduate summer school that will be held at Rhodes University, South Africa between January 15 and 24, 2013.

Colloquium and Seminar Organization, Placement, and Support

Thomas Corbitt and Gabriela Gonzalez will begin organizing a new summer outreach program designed to increase participation in graduate school in the LSC from under-represented groups. The program will be supported by Corbitt's pending CAREER grant, and will take place at LLO during the summer with a small number of undergraduate students. The students will undergo communication, math, verbal, and test-prep training, and will also perform research in groups under graduate student supervision. [24]

Distribution of Video Recordings of Talks

Web Materials

Brown is on the scientific advisory board for Kevin Lee's (UNL) proposal to fund Class Action Astronomy tools (See http://astro.unl.edu/classaction/). Brown will collaborate with Ed Prather (U Arizona) and Lee to develop think-pair-share questions on gravitational-wave astronomy. These will be incorporated into Class Action for use in the Introductory Astronomy Classroom. [35]

Curriculum Development

Members at Southern University are part of an ongoing effort to redesign the introductory physics course syllabi to include LIGO science, pushing to incorporate the usage of on-campus LIGO interactive exhibits into the courses [32]. In Hungary, members of Eotvos University will continue teaching a university lab using infrasound microphones [14].

The on-line cosmology curriculum being developed by CominskyâĂŹs [30] group includes a five-week module about gravity, black holes and the dark universe. It will be available for pilot testing for general education college courses beginning in the fall 2013 semester.

8.2.4 For Educators

Promote Faculty Workshops

Teacher Education Initiatives

Various programs will be supported that encourage the use of LIGO-related materials in classrooms. University of Western Australia will coordinate teacher professional development programs to promote this agenda, members of Syracuse will do the same, and Cominsky and the Sonoma State [30] outreach staff will promote the use of LIGO-related materials through the Educator Ambassador program [30, 35, 46].

Organize Teacher Workshops

The Oregon University group will continue to participate in the QuarkNet program [41].

Unified Teacher Materials Hub

8.2.5 For All

Support & Involve Ages: 18 - 23

Support & Involve Ages: 23 - 35

Support & Involve Ages: over 35

Lectures/talks/festivals/expo

Regular public lectures on LIGO research and gravitational waves will be given [5, 25, 28, 44], and a session on "The Extreme Universe" will be organized by Rowan as part of her presidency of the British Science Association Physics and Astronomy section [17]. Members of the RIT group will participate in the annual Imagine RIT festival, members of the Glasgow group will participate and give an invited lecture atthe British Science Festival, and Mikhailov will give a talk titled "LIGO: Laser Detection of Ripples in Space" at the Physics Fest at the College of William and Mary [11, 17, 28].

Create Open Source Educational Materials, Experiments, Applets

Web Courses

8.2.6 Other

Facilitate Conferences

UTB will host the 2013 Joint Fall Meeting of the Texas Section of APS, the Texas Section of AAPT and SPS October 10-2. Scheduled speakers include Nobel laureate Robert Curl, Barry Barish, and Gabriela Gonzalez. A session on gravitational wave astronomy is planned. 2013 marks the tenth anniversary of the Center for Gravitational Wave Astronomy. Events to commemorate the anniversary are being planned for October 2013 [43].

Web Presence

8.3 EPO Informal Education and Outreach Group Scope

8.3.1 Toys and Goodies

T-Shirts

Toys

Posters and Stickers

Aurore Simonnet will design LIGO outreach materials including LIGO stickers [30].

Origami

LEGOs

8.3.2 Visual Media

Comics

Cartoons

"Art, Beauty, Science" Project

Graphic Design

Visual Material Development: 3D Models, Animations, and others

Rodriguez at NorthWestern University will work on generating 3D visualizations for both technical and public outreach talks using the numerical relativity data from the Einstein Toolkit [26]. At RIT, Bischof and Whelan will work on a visualization of the geometry of gravitational wave propagation and detection [28].

Coordinating with the Society of Physics Students, Miller and Willis will seek to produce a secod brief video aimed at a general audience for the visualization of gravity through worldlines in a curved spacetime [2].

Manga

Slideshows

8.3.3 Audio Media

"Sounds of Gravity" Project'

The Montclair [25] team is developing a webpage of gravitational-wave sounds.

Development of Materials for Audio Media / Radio

Creative Musical Projects

Development of Web/PodCasts

Promoting Radio Placement of our Field

8.3.4 Film, Video, Animations

Development of Materials for Professional Broadcast & Documentary Media

If the grant proposal submitted to the NSF CRPA program is awarded, Joseph Giaime and Gabriela Gonzalez will collaborate with Louisiana Public Broadcasting and the LLO Science Education center, and develop a strategic multimedia partnership for outreach detailing the science and construction of the Advanced LIGO detector in the LIGO Livingston Observatory. The project seeks to not only produce a video centering on Advanced LIGO, but to explain some of the underlying science in small units that include video modules, computer applications, smart phone apps and simple at home experiments. Each information piece will link to an element of LIGO. The proposal was submitted to NSF and is awaiting review. There were some video segments produced and shown in local TV stations. [24]

Promoting Film(Hollywood) Placement of our Field

Thorne is pursuing the movie project "Interstellar" with Spielberg [9].

Development of Educational Videos for Web Publication

8.3.5 Interactive Media

Develop and Promote Games

Expansion to Multiple Platforms: iPhone apps, Android apps

Members of the University of Birmingham group will continue to develop interactive computer games, and will try to make games accessible on more platforms, including smart phones [6].

Development of Augmented and Virtual Reality

The development of a virtual reality tour of the LIGO Hanford site will be continued if there is sufficient interest. Otherwise members of the Eotvos group will develop animations of aLIGO component models [14].

Members at Eotvos are also developing a special media room in Budapest that is capable of video conferencing at an elevated, "virtual presence" level [14].

Developing, Organizing, and Providing Exhibitions

AEI plans to develop Einstein@Home multimedia demo systems that provide information about data analysis and gravitational wave detetion, to be incorporated into the preexisting Einstein Wave Bus [16]. Lindsey Johnson will work on her senior thesis project which involves creating a script for a proposed planetarium show about gravitational wave astronomy [44].

Work will continue on creating future installations of the large LIGO exhibit at sites across the U.S [40]. Riles will also help other interested scientists wishing to build interferometer exhibits [39]. The Glasgow group will seek to display their own traveling exhibit at various events, including the British Science Festival, Orkney Science Festival, Gravity Fields Festival, Edinburgh International Science Festival, Glasgow Science Festival, and other events [17].

Ghodrati will work on developing a prototype seismometer exhibit that includes an iPad app that prints seismographs generated by the users' motion. This "make a quake" exhibit will be the first component of a larger exhibit on seismology. If this effort is successful, a LIGO-specific version to demonstrate the effects of seismic isolation will be developed [39].

Science Museums and Planetariums

Members of Northwestern will continue promoting LIGO material through work at the Adler Planetarium and Astronomy Museum [26], and members of SLU will work towards projects to promote LIGO at the Hammond Children's Discovery Museum [33]. Members of American will help refurbish the planetarium and observatory at Howard University in Washington DC, and plan to include LIGO information and material as well [3].

Riles will continue to serve on the Ann Arbor Hands On Museum Board of Trustees, beginning to serve his 2nd 3-year term [39].

8.3.6 Print Media

Development of Brochures and Leaflets

The GEO600 brochure will be updated, in both its German and English versions, and UIB will develop trifold leaflets about gravitational waves to hand out during science fairs [5, 16].

Promoting In-Fiction Placement of our Field

Material Development for Printed Media, Newspapers, Magazines, and Others

Supervising Science Summaries

Work on the creation, editing, publishing, and translating of science summaries will continue [17, 30, 38].

Publishing LSC Newsletter and Magazine

The LSC has recently started a regular publication, the 'LIGO Magazine', with Andreas Freise [6] as Editor in Chief. While the main aim of the magazine is to enhance the communication within the LSC itself, the quality of the content and production have been carefully chosen such that the result will be suitable for several kinds of public engagement and outreach. The first issue has been published in September 2012, with feature articles and many fascinating pictures about the installation of the Advanced LIGO detectors. Currently this issue is only available online (as a pdf file) but already the download statistics from the webserver indicate an interest goes beyond our community with more than 1600 downloads, clearly dominating the server's bandwidth. The first issue will also be made available as a glossy print version to most LSC groups to be distributed to stakeholders and to be laid out in student areas.

Harry of Syracuse, Bischof of RIT, and Read of Fullerton will serve as editors for the new LIGO magazine [15, 28, 35].

Simonnet will contribute time to designing the LIGO newsletter format [30].

8.3.7 Performance Art

"Einstein's Cosmic Messengers" Solo Performance

The Glasgow group will host a concert performance accompanied by a public lecture of "Einstein's Cosmic Messengers" in October 2012 [17].

"Astrophysics and Dance"

Bischof and Campanelli (PI), in collaboration with faculty of the National Technical Institute for the Deaf at RIT, were awarded an NSF Communicating Research to Public Audiences (CRPA) grant. The project, entitled "CRPA: Astrophysics and Dance: Engaging Deaf Students in Science Education" (DRL-1136221) leverages 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. An educational website for the project, is under construction, and the storyline for the performance has been defined. http://astrodance.rit.edu/ [28].

Spoken Word

8.3.8 Up Close and Personal: Meet the Scientists

Interviews with LSC Scientists

"Travels of an Astrophysicist" Project

Blogs By LSC Scientists

Guided Tours

Guided tours will continue at LLO and LHO [24, 39].

8.3.9 Expanding Our Audience

Engaging through Social Media: Facebook, Twitter, and Others

Followers on Twitter will be kept up to date with regular tweets from AEI, Glasgow, UIB, and others [5, 16, 17]. The LIGO Facebook page will also be maintained [15].

Multilingual Efforts: Web, Translations, Foreign Tweets, and Others

With the continuous creation of new LIGO outreach materials, members will continue to work on translating these materials, both old and new, into foreign langauges. This work includes translating group websites [5, 6], translating the ligo.org pages into Spanish and Hungarian [14, 16], translating Einstein's Messengers into Portuguese and French [4], preparing Spanish captions for video clips such as scienceface episodes [5], updating foreign language Wikipedia entries related to gravitational waves [5], translating exhibit displays into Catalan [5], translating the LIGO virtual tour into

Hungarian [14]. Shannen Velasquez [4] has started translating some of the Science Summaries into Spanish.

Interfacing to LSC Diversity Group

Members of AEI will participate in the LSC Diversity Working Group, providing input on career issues, especially on the issue of transitioning careers to a science-based but not research-focused job [16].

Recruitment

Members will continue participating in the SACNAS meetings [15, 24, 43], as well as the TSAPS and NSBP-NSHP meetings [43].

New Websites

An overhaul of the ligo.org website will be undertaken, with the goal of creating "a single well-organized portal which leads to different aspects of LIGO (observatories, science, EPO, LSC, lab, etc.). The internals of the website will also be modified to better synchronize Spanish pages, and more documentation on the wiki for LSC members wanting to add and edit pages will be created [16, 27].

Several groups will be working on beautifying and upgrading their group outreach pages [5, 16].

The website www.scienceface.org will be completed, with the inclusion of additional information regarding scientific topics and the interviewed scientists. A new section of the website will also be developed to host a new series about gravitational wave research, cosmology, and astroparticles [16].

The website www.gravitycentral.org will be launched and linked to the GWIC internet portal [17].

An overhaul of the Einstein@Home website is planned [16].

8.3.10 Other

"Engaging Young Minds" Project

8.4 EPO Professional Outreach Initiative Scope

8.4.1 Internal Education

Teach LIGO to LSC members and Other Professionals

Teach the Art of Funding

Outreach Abstracts

Teach Effective Communication

The American group will begin write a document on political outreach, developing a handbook for use by other LSC PI's when communicating with political officials, journalists, and other opinion makers in the political realm. They find an appropriate partner on the political side of campus at American and begin a dialogue on how to do this, aiming at sharing a student the summer of 2013 [3].

Interface to LSC entities: WebCom, P&P, LAAC, and Others

Dictionary & Handbook Project

8.4.2 For Broader Scientific Community

APS, AAS, AAAS, IEEE, OSA, and others

S. Larson has a long history of building ties to the astronomical community in gravitational wave physics, billing the use of gravitational waves as a tool for studying astrophysical systems. Now, in advance of the first detections, is the most opportune time to begin encouraging broader awareness of our science. This year USU will start exploring how to have a bigger presence in this regard (e.g. organized poster sessions and booth displays at AAS meetings; production of materials geared toward reaching out to scientists beyond the gravitational wave community) [44].

Facilitate Employment, Recruitments, and Conferences

Professional Tutorials through Web, Radio, WebCasts, PodCasts

GWIC

The maintenance of the GWIC internet portal will be discussed, the editorial system will be set up, the content agreed and the portal published [16].

8.4.3 For Amateur Scientists

Distribution of Environmental Data; Enable Access and Use

Engage, Excite, and Facilitate Amateur and Citizen Science

Facilitate Crowd Sourcing

8.4.4 For General Public

Printed/Broadcast Media

Highlight Spinoff Tech

Development of Professional Exhibits

8.4.5 Other

Enable and Facilitate Industrial and Corporate Relations

Facilitate/Provide Science Interpretation for Policy Making

S. Larson is the chair elect of the 4 Corners Section of the American Physical Society, participating in the Congressional Hill visits each year sponsored by APS, and visiting the Utah delegation about science funding and science activities in Utah and in the USU group [44].

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10 Appendix: History and Highlights

10.1 EPO Committee and Coordination Scope and History:

10.1.1 MoU Review, Reporting, Coordination

The LSC MoU Review Panel included members familiar with EPO goals and activities.

10.1.2 Press/Media Relations

Many groups have made press releases that have had significant press coverage. These include: "Getting ready for next time: European gravitational wave community strengthens its space collaboration", "Onine new gamma pulsars: Discoveries in Fermi telescope data thanks to method used in gravitational wave astronomy", and "Squeezed laser will bring gravitational waves to the light of day" from [16], and ones that resulted in a news interview http://www.youtube.com/watch?v=GAilAbyhcG4) and two full page newspaper articles http://www.uib.es/depart/dfs/GRG/news/prensa/prace_baleopolis.pdf [5]. Birmingham [6] group has participated to 'Stargazing live' events with the BBC in 2012 and is currently planning further joint events for 2013. Efforts have also been made to interact with journalists individually, informing them about gravitational wave projects [16]. Others, such as [12, 16] have achieved high media exposure for their research, with viewers reaching millions. Earlier this year S. Marka addressed hundreds of global leaders at the Science & the City Gala that gathered top politicians, renowned scientists, leaders of industry, and educators [12].

10.1.3 White Paper Editions

Cavaglia was the lead author of the first LSC White Paper on Education and Public Outreach (T1000127), and was the editor of the 2011 revision of the EPO white paper [40].

10.1.4 Compilation of Statistics, Efficacy, Performance Measures

10.1.5 Award, Prize, Fellowship Surveys and Highlights

LSC participants of all ages have received awards and recognition in the previous year. These include L. Matone's undergraduate student Douglas Powers who was offered the pretigious Rabi Scholarship [12], graduate student Alex Vano who was awarded a FPU grant [5], I. Bartos who was selected as one of the "Rising Stars of Science: The Forbes 30 Under 30" [12], and S. Marka won the Blavatnik Award of NY Academy of Sciences for his work in multimessenger astronomy [12].

10.1.6 R&D on Effective Communication

10.1.7 R&D on EPO and Outreach Innovation

Kalogera worked towards strengthening the connections and interactions between the LSC and the astronomy and astrophysics community whenever opportunities arise. She served on the P&P committee with a particular focus on: identifying astronomy conferences where talks related to LIGO could be presented and advertising them to the LSC, suggesting LSC speakers for invited and contributed talks at astronomy conferences, and thinking about best strategies for LSC participation in astronomy conferences. [26]

Cavaglia started the monthly 'Oxford Science Cafe' in Oxford MS: http://www.phy.olemiss.edu/oxfordsciencecafe/. Six meetings in fall 2011 - spring 2012 [40].

10.1.8 GW History Project

10.1.9 Formal Education Group

In 2011, Cominsky [30], Katzman [23] and Ingram [22] were appointed as co-chairs of the EPO subgroup on formal education 5. At the request of Beverly Berger, then NSF Gravitation Program Director, Cominsky [30], Katzman [23] and Ingram [22] authored a white paper on formal education, which was then submitted to NSF.

10.1.10 Informal Education Group

In January 2012 Hendry was appointed as chair of the EPO sub-group on informal education. In this role he coordinated the LSC's exhibition at the 2nd USA Science and Engineering Festival, Washington DC, Apr 2012 [17].

Cavaglia spearheaded and also served as PI of the LSC outreach award Astronomy's New Messengers. He organized and direct the tour of the LIGO exhibits across the U.S. Cavaglia and Rankins organized and coordinated outreach activities in schools and colleges, and helped with professional development of teachers on LIGO-related science. Public lectures and outreach events were organized on a regular basis [40].

Shawhan was appointed as the coordinator for Science Summaries.

Read, Cominsky, and Stuver founded the social media group.

10.1.11 Professional Outreach Group

Zsolt Frei (Hungary) has joined ASPERA-2. ASPERA is an ERANET (European Research Area Network) for Astroparticle physics. Frei negotiated terms and is participating in meetings as representative of Hungary (votes on the Governing Board as proxy to the official delegate who represents one of the Hungarian funding agencies). His aim is to keep gravitational wave physics among the topics of common calls. ASPERA works on about 6 key topics within astroparticle physics, one being gravitational wave physics. One aspect is outreach. (There will also be common calls for grants, working out a decadal-type survey, etc.) The first ASPERA organized outreach effort took place in October, 2009. Frei also sorganized a "Hungarian National Day" for ASPERA on October 15, 2010. All Hungarian scientists involved in the field gave talks to ASPERA representatives. [14]

10.1.12 National and International Partnerships

Nigel Bishop (Rhodes University) and Fred Raab [22] initiated the workshop on Gravitational Wave Astronomy (GWA2012) in Johannesburg, South Africa, May 31-June 1, 2012. At the meeting the topic of venues for promoting GWA and collaborative work within the LSC in SA was discussed. Manuela Campanelli [28], Fred Raab [22], and Gabriela Gonzalez [24] was part of the Scientific Organizing Committee. Among others Gabriela Gonzalez [24], Bernard Schutz [16], Fred Raab [22], Manuela Campanelli [28], Luis Lehner (Perimeter Institute, CA) presented background talks. The meeting was also supported by the South African Minister of Science and Technology, Minister Naledi Pandor MP, as an initiative to promote and grow gravitational wave astrophysics throughout Africa.

10.2 Formal Education Group Scope and History

10.2.1 For Elementary School Students

Support & Involve Ages: 4 - 7

Peter Beyersdorf gave a presentation on the mysteries of science to the 3-5 year old students in the San Jose State University on-campus preschool [29]. Each year, Brian Lantz has taken some science demonstrations to local first-grade school classes. He typically uses liquid nitrogen to describe some of the effects of temperature and heat transfer – making ice in 30 seconds, freezing flowers, shrinking balloon animals - and concludes by making liquid nitrogen ice cream [34].

Support & Involve Ages: 7 - 12

Groups have been involving young children in hands-on science through science fair projects and robotics competitions. Hendry organized a series of school science fair projects for more than 50 Scottish primary schools, and developed interactive multimedia resources and practical experiments that allow students to explore various aspects of gravity [16]. Z. Marka mentored a team of 4th and 5th graders from The School at GECo University at the Robocup Junior 2010 robotics world championship in Singapore. The team won the award for "Best Use of Sensors" [12]. Doug Beck coached two teams of six 5th graders at Hoover Community School in Redwood City in a "FIRST LEGO League" competition held at Google Headquarters. One team made it to the next round of competition as one of three finalists [34]. Andreas Freise [6] gave a presentation 'How to grow a planet' at the Monkton Wylde family science week. The staff at UTB performs a set of demonstrations collectively known as the Physics Circus at elementary schools. The staff also participatse in elementary school career day events where they discuss gravitational wave astronomy and LIGO [43].

GW Picture Books

Curriculum Development

Through the 8-week long pilot program, "Einsteinian Physics for Young People", David Blair introduced primary school students to curved space geometry and spacetime. The results of this program have been written up for journals and world Conference of Physics Education Materials, and have been uploaded in DCC document G1200795-v1. Blair is also involved in producing "Gravity: A Play for the Whole Class", a play tracing the history of thought about spacetime and gravity, from Pythagoras to Einstein to Hawking. [46].

10.2.2 For Middle and High School Students

Activities, Demos, and Events

LSC members have brought physics demos to a number of middle school and high school classrooms. Cavaglia performed dmonstrations related to the physics of space and LIGO among other gneral physics demonstrations at Rankin Middle School, where he presented to over 100 kids and parents [40]. Events such as a World Space Week celebration and astronomy club meetings in Brownsville, TX and Milwaukee, WI were organized to reach out to reach out to local high schools [43, 45].

High school students have also been invited onto university campus to participate in the program "Playing at Being Einstein" which consists of a showing of a homemade documentary on GWs, as well as time spent playing games such as Space Time Quest and Black Hole Pong developed by gwoptics [5].

Birmingham [6] organized several visits to secondary schools in England and one 'school day' at the university. These events were supported by the IOP and primarily targeted at A-level students from schools with no or little science teaching/opportunities. This grant has so far funded a visit to Edgbaston High School for Girls on 6 May 2011, an outreach event at University of Birmingham on 12 December 2011 for Holy Trinity International School (a short article describing this was published on the Institute of Physics' website), a GW activity day at Bishop Ullathorne on 2 Feb 2012, and a large public outreach day in conjunction with Birmingham's Particle Physics Group to be held on 24 June 2013 at Bishops Cleeve School.

Andreas Freise [6] and Ilya Mandel [6] take part in a online video link project with secondary schools "Ask a researcher - SKYPE links to you classroom".

The group at UTB presents the Physics Circus at middles schools throughout the Brownsville area. Prior to the demonstrations students view a presentation about research performed in the Department of Physics and Astronomy that highlights gravitational wave astronomy and LIGO. They have presented to approximately 1000 middle school students so far in the 2012-3 academic year [43]. UTB staff have also manned department telescopes at local middle school astronomy events held in the evening and early morning [43].

Beginning in the spring semester of 2013 the astronomy group at UTB has made department telescopes (including a 16-inch Schmidt-Cassegrain telescope) available to the public at a local state park on the last Friday of the month. UTB staff members are available to provide information to visitors, and visitors are invited to a PowerPoint presentation at the park when viewing is prevented by weather conditions [**?**].

Talks and Lectures

High school students were also beneficiaries of many outreach talks, including the ones which were given at the SciBono Science Discovery Centre (Jonannesburg, South Africa), Pasco High School (Pasco, WA), Ochoa Middle School (Pasco, WA) [24]. Three outreach lectures were given to 7th graders in Michigan, a lecture on waves, interferometry, and LIGO was given to high school students in Texas, and a general talk "El origen del Universo" was given to high school students in Spain [5, 36, 39].

Monday Night Physics Lectures are occasional lectures in which physics faculty at UTB present talks on physics and related areas on the last Monday of the month. Although the talks are open to the public the lectures are heavily promoted in the high schools so that the majority of attendees are

Figure 10.1: Physics Circus- The UTB Physics Circus is a popular outreach event. A presentation describing UTB's gravitational wave research is shown prior to the circus.

high school students. An average of 80 people attended each lecture in 2012-3. Students are informed of gravitational wave astronomy research that takes place in the department [43].

Figure 10.2: Monday Night Physics lectures at UTB take place periodically during the academic year. The audience is comprised mainly of high school students.

Summer Programs

This past year, twenty high school students participated in the 8th Astronomy Ambassadors Academy between June 14-29, 2012. The program included a trip to the McDonald Observatory and to a section of the Very Long Baseline Array radio telescope in Ft. David, Texas, and allowed students to work on the Low Frequency All Sky Monitor that is being constructed. In addition, the Upward Bound summer program introduced students to various aspects of gravitational wave astronomy [43].

Research Involvement

The Border Land Astronomical Study and Research Society (BLASARS) invited students from 21st Century Astronomy Ambassadors Academy to meet weekly on university campus to discuss LIGO research. In 2008-2009, eight students participated in BLASARS, and seven students participated in 2009-2010 [43].

Some high school students were actively involved in hands-on research. Such opportunities were provided for example for New York area high school students James Wooddall, Doug Powers (Regis High School) and Jonathan Yee (Bronx Science School), who worked on mind-opening electronics projects [12]. Students at Loanger High School formed a team to work on a research project investigating 60 Hz environmental magnetic field noise. Parkinson put together a proposal with activities similar to those at Loanger High School (Project STAR - Student Teams Active in Research) [33]. Brian Lantz has also mentored numerous high school students in projects investigating the performance of damping struts for the output mode cleaner frame, the angular sensing in the seismic platform interferometer, among other projects [34]. Brown involved a high-school student in an investigation on noise in the LIGO detectors, and two high school students assisted with detector characterization studies with the Michigan group [35, 39]. The San Jose Group set up an arrangement with a science teacher at Wicox High School in Santa Clara, CA to provide research opportunities during the academic year to interested high school students [29].

UTB staff participates in high school recruiting events that take place at local high schools. Students are informed about gravitational wave astronomy as well as scholarship opportunities at these events [43].

Other high schools are starting to show interest in sending students to start LIGO-related research projects: plans are being developed for Kentwood High School and St. Thomas Aquinas High School [33].

"Office Hours" with LIGO Scientists

Andreas Freise and Ilya Mandel [6] take part in a online video link project with secondary schools âĂIJAsk a researcher - SKYPE links to your classroomâĂİ. Similarly Chiara Mingarelli was invited to participate in the ASTRON's (Netherlands Institute for Radio Astronomy) outreach event for Girlsday (www.girlsday.nl/girlsday-in-english.html), launched by Queen Maxima of the Netherlands. This allowed 10-15 year old girls, who were spending the day at ASTRON, Netherlands, to ask questions via Skype about being a female astrophysics researcher.

Curriculum Development

In the realm of Curriculum Development for high school, groups have taken on supportive roles by mentoring students in their experiment projects, but have also pushed for introduction of LIGO-

related activities into the classroom and even the restructuring of high school science syllabi to include gravitational-wave science. Through the STEM Ambassadors' scheme, students and postdocs make regular visits to schools and mentor students on their experimental investigations [17]. A one-day program called "Curved Space and Quantum Weidness" was tested on students with positive feedback (see DCC G1200794-v1) [46], and lessons developed for gravitational-wave science at the high school level are part of a paper accepted for publication by the American Journal of PHysics [26]. Efforts are being made to introduce science enrichment activities, including ones involving LIGO, to junior high schools as well [4]. Working on the Scottish Qualifications Authority Physics Qualifications Design Team, Hendry contributed to the development of a new syllabus for high school physics, which will include material on special and general relativity for the first time [17].

10.2.3 For University Students

Promote and Support REU, SURF, Undergraduate Research

Groups have continued to support various programs for undergraduate research. REU students Oleg Kiryukhin, Mikhail Korobko, Davide Gerosa, and Matthew Heydeman were supervised by Miao and Chen, and REU student Joseph Iafrate was supervised by Cesar Costa, Christina Torres, and Gabriela Gonzalez [9, 24]. In addition, Joseph Hill, Ricardo Marquez, Martin Harrington, Joseph Coleman, and Ryan Staten were supervised by Mario Diaz, Soma Mukherjee, Volker Quetschke, Joe Romano, and Christina Torres and were supported by an REU grant during the summer [43]. The REU grant "REU site: High Performance Computing and Data Visualization" was continued for RIT [28]. Gustafson mentored Kevin Kuns and Ilya Belopolski this summer. Of the 16 SURF students Gustafson has mentored, four have gone on to LIGO-based graduate programs [39].

Students from Italy were hosted by Cavaglia, Corsi, and Marka within the LIGO-INFN summer program for undergraduates [9, 12, 40]. International involvement with undergraduates was continued in the IREU program, which sends 12 students abroad each year to labs engaged in gravitational wave research. This summer, 14 students were sent abroad for two months each [37]. In another project designed to train Indian undergraduates in the basics of GW data analysis, a mock data set with Newtonian chirp signals added were analyzed using Matlab and python [20]. Students Aaron Buikema, Alex Mellus and Benjamin Hubbert were were hosted in Birmingham UK by Andreas Freise, Ilya Mandel, and Alberto Vecchio [6].

Other groups have also supported undergraduate research outside of official programs. These students work on a wide range of projects, including the characterization of aLIGO suspensions (Abi Polin), creation of animations of different oscillation modes of neutron stars, LIGO data folding, data characterization techniques related to GW bursts, development of an electrical heater (Jesus DeHaro), modeling of the deformation of a mirror using finite element analysis (Cynthia Vazquez), and more [5, 20, 24, 29, 39, 41].

Support Summer / Winter Schools and Rigorous Learning Events

The eighth annual Gravitational Wave Astronomy School (GWASS) was held May 28-June 8, 2012 on South Padre Island. Nineteen students from 3 nations and 18 institutions attended this event, which included talks by scientists from several institutions [38, 43]. In the 2010 incarnation of GWASS, 27 sudents from 9 nations and 22 institutions attended [43].

In 2011 there was also the Tougaloo College Physics Summer Camp, which featured lectures on astrophysics, relativity, black holes, and gravitational waves. Point of contact: Marco Cavaglia [40].

Colloquium and Seminar Organization, Placement, and Support

Much effort has been made to reach out to physics and astrophysics undergraduates to inspire students to research with LIGO, in addition to informing students about gravitational-wave astronomy in general. Seminars focused on career development were given by Riles at a community college in Michigan and by Smith at UC Irvine [15, 39]. Inspiring talks about the research done at LIGO include "Searching for Gravitational Waves from Periodic Sources" given to students in the RIT astrophysics program, a presentation on gravitational wave science given to Carleton College students, a colloquium talk on the quantum optics aspects of GW astronomy given in a 200-seat lecture hall full of University of Toronto students, and a presentation on LIGO research at AstroFest at Columbia University, and more [7, 10, 12, 13, 28]. Gonzalez served in a panel on "What to Expect in College: A Professor's Perspective" panel for incoming LSU freshmen in the LSU LA-STEM HHMI program, a mentoring program for helping struggling STEM undergraduates in their first years in College. [24]

Distribution of Video Recordings of Talks

Web Materials

Educational materials directed towards university-level students have been made available on the web. These include Mathematica demos, full courses in gravitational wave physics, and interfaces for asking questions to LSC members.

Mathematica demonstrations have been developed to illustrate concepts in gravitational wave physics, and include: 1) Antenna Patterns for a Laser Interferometer Gravitational Wave Detector, 2) Gravitational Wave Frequency Distribution for Two Orbiting Point Particles, 3) Surface Of Revolution From Wavelets, suitable for visulizing wavelets in 3-d, 4) Scalogram of Gravitational Wave from a Binary Black Hole Inspiral, 5) Newtonian Gravitational Wave Chirp Signal from Merger of a Compact Binary [20].

Interactive applets demonstrating key technologies [6] and concepts of gravitational wave science are available with source code online. This includes, seismic isolation via pendulum suspension, interference in a Michelson interferometer, the chirp sound of an inspiral signal, stimulated emission in a laser and much more (www.gwoptics.org/processing)

Online course materials are available for one term of introductory general relativity, one term fo gravitational wave source and data analysis, and one term of gravitational wave instrumentation [9]. Einstein Online contains an introduction to gravitational radiation and to gravitational wave detection [16].

The Ask-A-Scientist program allows students and educators to pose questions on LIGO, gravity, and related physics or astronomy concepts through web-based text and videos. A trial instructional video on interferometry is `currently viewable here` [36].

Curriculum Development

Undergraduates in many institutions have received lectures on gravitational waves and LIGO from Riles [39], Cavaglia [40], Frey [41]. A course focusing on gravitational-wave physics was taught at Caltech, in which graduate students were assigned work on various aspects of the Advanced LIGO upgrade [9]. S. Marka, Matone, Bartos, and Z. Marka advocated the field of gravitational wave physics/astronomy and the exciting beauty of science through their classrooms [12], and Zsolt Frei incorporated 4 weeks of lectures about gravitational waves into his Astrophysics II course [14]. A full

course titled "Gravitational Wave Astrophysics" was taught for MSc students, and gave an overview of gravitational wave physics, hardware and software insrumentation at LIGO, and the basics of detector characterization and gravitational wave data analysis [14]. The 2009 International School on GNR, funded by APCTP (Asia Pacific Center for Theoretical Physics) was run by members of KGWG and included sessions on gravitational wave astronomy [19].

10.2.4 For Educators

Promote Faculty Workshops

Gregory Harry and Jonathan Newport attended the AAPT Conference in July 2012, where they distributed LIGO literature and sought to increase LIGO involvement with physics teachers [3].

Teacher Education Initiatives

Ben Farr collaborated with K-12 teachers throughout the year and brought examples and concepts from research into the classroom activities and curriculum [26]. Christensen also gave a presentation about LIGO and gravitational wave science to 18 high schools students at the Carleton College Summer Teaching Institute [7].

`Lectures` about gravity, General Relativity and LIGO, as part of a teacher professional development workshop at Sonoma [30] State University. These lectures, as well as the slides and other lectures that were part of the workshop can be `downloaded here`.

Organize Teacher Workshops

Various professional development workshops for teachers have been coordinated. Williams, Parkinson and Yoshida coordinated a workshop for 30 local middle school and hig school science teachers [33]. Cavaglia gave an introductory talk at the LIGO+Quarknet Teacher Workshop at University of Mississippi in June 2012, and Unversity of Oregon also sponsored a Quarknet program [40, 41]. The Eotvos group also helped organize the third annual workshop of the ET projectin Budapest in 2010 [14].

Unified Teacher Materials Hub

10.2.5 For All

Support & Involve Ages: 18 - 23

Support & Involve Ages: 23 - 35

Support & Involve Ages: over 35

Lectures/talks/festivals/expo

LSC members have over the years given numerous public lectures and talks, exposing members of the general public to the field of gravitational wave science. These talks include, among (many!) others:

2009

“Light of the Living Dead - The Remarkable Radiation from Neutron Stars” given in Ann Arbor for Halloween, which was videotaped and available for viewing at http://lecb.physics.lsa.umich.edu/CWIS/browser.php?ResourceId=1734 [39].

“A Matter of Life and Dead: How Black Holes Do It” was presented within the Public Lecture series of the Columbia Astronomy Department [12].

Public lecture and concert at the University of Florida, with a half-hour lecture on gravity followed by the “Einstein’s Messengers” multimedia concert, presented to about 225 people [37].

2010

Public lecture given at the Asia Pacific Center for Theoretical Physics, Pohang, Korea [35].

Public lecture on gravitational waves to the University Neighbors Lecture Series given by Saulson [35].

Wallace Herbert Memorial Lecture was delivered in Ruston, LA, as an event associated with the LIGO tour exhibit at the IDEAs center hosted by Louisiana Tech [24].

World Science Fair in New York: Thorne lectured on gravitational wave physics [9].

“Results and Challenges in Multimessenger Searches for Gravitational Waves” was presented by Imre Bartos [12].

2011

“Ripples in the Universe: Catching Gravitational Waves with LIGO” was a public talk given at Purude University in Westville, Indiana [26].

“Science Unwrapped” public lecture series at Utah State University [24].

“Sounds of space-time” was an inaugural public talk given on the occasion of the LIGO traveling exhibit at the Stafford Air and Space Museum [40].

“All black holes great and small” was a public talk given on the occasion of the tear-down of the LIGO traveling exhibit at the Stafford Air and Space Museum [40].

2012

“Echoes in Gravity” was given as part of a month public lecture series on astronomy, presented to a full lecture hall of 20 people [10].

Several public talks at the SciBono Science Discovery Centre in Johannesburg, South Africa [24].

Public talks given during the Transit of Venus in June 2012 [17].

Alberto Vecchio [6] participated to a Cafe Scientifique podium discussion in a science museum on “What is time?”.

The multimedia public lecture ”Gravitational Waves: Listening to the True Music of the Spheres” was delivered by Bernard Schutz [16] in several venues: in 2009 in Potsdam, Germany; in 2010 in Oporto, Hanover, St Louis, Beijing, and Palo Alto; in 2011 in Southampton UK, Cardiff Wales, the Azores, and Potsdam again.

The idea of Science Cafe is to have regular public outreach lectures. It was conceived by Cavaglia who organized and hosted the Oxford Science Cafe [40] and it has since been established in Rochester [28] and it has involved speakers from various institutions [2]. Similarly, Cafe Science is a series of informal discussions led by Columbia University faculty that targets the general public, and a presentation on “The birth and death of black holes” was given to 50-60 inquisitive minds as part of Cafe Science in 2012 [12].

Expos, festivals, and other public events have been hosted and supported by LSC members. “An Evening Under the Stars” was a public event for the inauguration of the UTB-CGWA Astronomical Observatory, which saw around 2000 people in attendance [43]. Galileo Night allowed people to view the night sky with telescopes in Cameron County, TX [43]. RIT-CCRG faculty participated in the annual Imagine RIT: Innovation and Creativity Festival where they staffed a table titled “Can't you see it? It's a black hole!” [28]. S. Marka was a co-PIs (Cavaglia (PI), Reitze, Hendry, Riles (co-PIs)) preparing and organizing the Astronomy's New Messengers exhibit for the 2010 World Science Festival. The exhibit was a definite success with thousands of visitors having a blast [12]. Z. Marka also co-chaired the Science Expo 2012 at The School at Columbia University, where she coordinated the astronomy and astrophysics exhibits. The event enabled hundreds of excited kids to roam the science exhibit and interact with dozens of world-renowned scientists and perform hands-on experiments [12]. Members of the Columbia group also participated in the Science Career Day organized by Women in Science [12].

The University of Birmingham group has developed their own exhibition called âĂŸLooking for Black Holes with LasersâĂŹ, which has been used regularly at various prominent exhibits across the UK since 2010. The exhibit consists of hands-on activities covering topics in astrophysics, data analysis and optics. This includes a Michelson interferometer, model suspension, âĂŸlycra universeâĂŹ and interactive computer games and animations. The exhibit has been used at the British Science Festival 2010, the national Big Bang Fair 2012, Gravity Fields Festival 2012, the BBCâĂŹs Stargazing Live Birmingham events 2012 and 2013 and most recently an event with the Birmingham particle physics group in conjunction with the University of Birmingham Arts and Science Festival and National Science and Engineering Week 2013. As a result the exhibit has been seen by thousands of people over the last 3 years. Articles summarising the 2013 Stargazing event written by group member, Chiara Mingarelli, were published in the UK's Institute of Physics Women in Physics newsletter and the University of Birmingham's College of Engineering and Physical Sciences newsletter. The next planned use of the exhibit is at the Cheltenham Science Festival in June 2013 – regarded as the premier science festival in the UK [6].

Create Open Source Educational Materials, Experiments, Applets

Web Courses

10.2.6 Other

Facilitate Conferences

Cavaglia co-organized the First Mediterranean Conference on Classical and Quantum Gravity (MCCQG) which was held in Kolymbari, Crete (Greece), September 14-18, 2009. Laura Cadonati (UMASS) represented the LSC at the conference as invited plenary speaker [40].

Web Presence

10.3 EPO Informal Education and Outreach Group Scope and History

10.3.1 Toys and Goodies

T-Shirts

LIGO-related T-shirts have been designed and distributed during science events. These include the "Black Hole Hunter" T-shirts and ones seen here: https://www.facebook.com/photo.php?fbid=407947559239794&set=a.407914035909813.96194.273304639370754&type=3&theater [5, 40].

Toys

LIGO yoyos and laser pointers were produced and distributed to kids at science events. Point of contact: Marco Cavaglia [40].

Posters and Stickers

Aurore Simonnet [30] has designed LIGO and LSC stickers which have been distributed to LSC members as well as at various science festivals. If you would like to distribute these stickers, please send mail to Lynn Cominsky, and indicate the quantity and postal mail address for shipping.

Origami

LEGOs

10.3.2 Visual Media

Comics

Cartoons

"Art, Beauty, Science" Project

Graphic Design

Visual Material Development: 3D Models, Animations, and others

Materials designed to help visualize the science behind gravitational waves and other aspects of general relativity have been developed by several LSC groups. One product was a computer applet that can be used to demonstrate the function of select systems in a gravitational wave detector [6]. A flash payer demonstration on gravitationa waves, interferometry, and LIGO in general was developed for the Ann Arbor Hands-On Museum [39]. The collaboration has also produced high-quality animations of black hole mergers, which are hosted in the Albert Einstein Institute multimedia archive at http://numrel.aei.mpg.de/Visualisations/. The Center for Computational Relativity and Gravitation at RIT has generated black hole merger waveforms acompanied by animated movies, available at http://ccrg.rit.edu/downloads [16, 28]. A 3D visualization software developed for the Einstein@Home data analysis project allows users to explore the Doppler effect in a binary pulsar system. Users can generate, view, and modify binary pulsar systems and their radio pulsations with this software which can be found at http://einstein.phys.uwm.edu/radiopulsar/html/topic4.php [16].

Manga

Slideshows

UIB has produced several slideshows on the history and science of LIGO, available online: 1) http://grg.uib.es/publico/aprende/historia.phpA brief history of gravitational waves, 2) http://grg.uib.es/publico/aprende/intro.phpAn introduction to gravitational waves, 3) http://grg.uib.es/publico/aprende/detectores.phpAn introduction to gravitational wave detectors [5].

10.3.3 Audio Media

"Sounds of Gravity" Project'

Development of Materials for Audio Media / Radio

Creative Musical Projects

The "sounds" from pulsars, CBC sources, bar mode spindowns and black hole normal modes were creatively combined into a short appealing musical composition suitable for use during public lectures and freely available at http://www.aigo.org.au [1].

Milde Science Communication developed "gravitational wave ringtones" for cell phones, which can be downloaded from http://www.ligo.org/multimedia [16].

AEI organized a closing event for the IYA in Brandenburg, a crossover music/art/astronomy project in cllaboration with the University of Potsdam, the Astrophysical Institute Potsdam, and the Nikolaisal concert hall in Potsdam, performed on December 4, 2009 [16].

Development of Web/PodCasts

AEI produced a series of podcasts that illustrate the experimental aspects of gravitational wave research [16]. Other podcasts include "Listening to Gravitational Waves: A New Window on the Universe" (point of contact: Gareth Jones), and the 10-episode series "Titanium Physicist Podcast" which can be found at http://itunes.apple.com/ca/podcast/the-titanium-physicists-podcast [40].

Promoting Radio Placement of our Field

10.3.4 Film, Video, Animations

Development of Materials for Professional Broadcast & Documentary Media

LSC collaboration members have appeared in television specials, including Rowan and Hough who were featured in a short film on gravitational wave astronomy that was commissioned for BBC Newsnight Scotland and shown nationally, and Gabriela Gonzalez who was interviewed about LIGO for the "Fabric of the Cosmos" series for NOVA [17, 24].

DFG Science TV has a 10-episode series called "The Wave Hunters" that was produced by young researches at AEI Hannover. All the episodes are available for viewing online at here [16]. Along with SiVIDEO Television Production Services, UWA/Gingin produced the six-minute video "LIGO-Australia: Discovering the Dark Side of the Universe" which is available on the AIGO Project webpage http://www.aigo.org.au and YouTube, and on DVD format [46].

Promoting Film(Hollywood) Placement of our Field

A TV movie has been produced about astrophysics, with a special heavy emphasis on gravitational wave physics and LIGO itself. The 42 minute full-HD program was broadcasted in August 2010 for Hungarian Public Television [14].

Development of Educational Videos for Web Publication

Produced as part of an undergraduate general relativity class, a video that combines computer-based animations with film and special effects is available here and illustrates geometric concepts from special relativity [2].

10.3.5 Interactive Media

Develop and Promote Games

Black Hole Pong: 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. Developed by the gwoptics group at the University of Birmingham in UK [6]. (See Case Study in Section 10.6 below for further details).

Space Time Quest: players take on the role of the principal investigators of an interferometric gravitational wave observatory, selecting the location for their detector and designing it to fit within the budget of their project. Players can then turn on their detector and look for gravitational waves, and the players' scores are determined by how deep into space they can detect gravitational waves [6].

Black Hole Hunter: developed as 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, this game allows people to search for the gravitational wave signals of two colliding black holes in static noise streams [6, 8, 16, 17, 31].

Slingshot: players in this game must strategically use the warping of spacetime created by planets to launch projectiles at their opponents' spacecraft on the opposite side of the screen [28].

Playing at Being Einstein: a video games stand presented at "Street Alicante Science". More information at http://www.uib.es/depart/dfs/GRG/news/sciencefair2012.html [5].

Graviquiz: an online quiz in Spanish designed to test the player's knowledge of gravitational wave detection, located at http://grg.uib.es/publico/juega/quiz/index.php [5].

Expansion to Multiple Platforms: iPhone apps, Android apps

Development of Augmented and Virtual Reality

Members at Eotvos have put together a virtual tour of the LIGO Livingston site by painstakingly stitching together numerous photographs of the laboratory. The current version of this tour is available at http://www.net3.hu/ligo/ [14].

Developing, Organizing, and Providing Exhibitions

"Astronomy's New Messengers", funded by an NSF outreach award, consists of a small traveling exhibit and a large-scale exhibit with an innovative art component. A more detailed summary of the design, development and display history of "Astronomy's New Messengers" can be found in the following section.

The traveling exhibit has traveled all over the country, and has been hosted and displayed at the following locations: Adler Planetarium (Chicago, IL), University of Mississippi Museum, Arkansas State University (Jonesboro, AR), Rhodes College (Memphis, TN), Agnes Scott College (Decatur, GA), University of Florida (Gainesville, FL), University of South Alabama (Mobile, AL), LIGO Science Education Center (Livingston, LA), Louisiana Tech University (Ruston, LA), LSU Middleton Library (Baton Rouge, LA), Southeastern LA University (Hammond, LA), Stafford Air and Space Museum (Weatherford, OK), SSU Clark Planetarium (Porthsmouth, OH), Washington DC, Dallas Texas, Brazos Valley Museum of National History (Bryan, TX), and Embry-Riddle Aeronautical University (Prescott, AZ) [13, 36, 40]. The large traveling exhibit premiered in June 2010 at the World Science Festival in NYC [37, 40] and was displayed at the Science Central Museum (Fort Wayne, IN). At many of these events, Cavaglia who served as the PI gave public talks, and at the World Science Festival he participated as a panelist in the public lecture, "Astronomy's New Messengers: Science and Design Collide". More information on the exhibit can be found at http://phy.olemiss.edu/LIGOexhibit/

[40].

Other portable exhibitions related to LIGO include rollup displays on gravitational waves and gravitational wave detectors used at Street Science Alicante [5], portable displays promoting gravitationa wave and multimessenger astronomy used in a UK-wide coordinated program of public observing events and the Highlights of Physics in Koln as well as the Night of Astronomy in the Hannover town hall [16], the interactive exhibition "Can You Hear Black Holes?" which has been displayed at museums and science festivals throughout the UK [16], and the exhibition "From Galileo Galilei to Gravitational Wave Astronomy" which has been displayed at numerous sites including Hannover University [16].

The "Einstein Wave Bus" is a traveling exhibition as well that presents gravitational wave astronomy. The project initially focused on displays in schools, but has since been displayed at planetariums and astronomy fairs such as: The 6th International Astronomy Fair in Villingen-Schwenningen (September 2011), a school observatory and planetarium in Rodewisch (September 2011), an observatory and planetarium in Suhl (November 2011), Galileo-Park in Lennestadt/Meggen (December 2012), MNU Bundeskongress (April 2012), and the conference 100 Years After Einstein in Prague (June 2012). The interactive displays were also present at the biennial open day at AEI in Potsdam, an event organized with other institutes on campus that drew about 2,500 visitors [16].

LSC members have also coordinated exhibits and presentations at various Science Week and festival events including the "Scottish Solar System" project for International Year of Astronomy [16], the "Gravity Beyond the Apple" show for International Year of Astronomy [16], activities at the Spanish National Science Week [5], the "How Do You Smash Black Holes in a Supercomputer" exhibit at the annual ImagineRIT festival seen by tens of thousands of people [28], a gravitational wave and LISA presentation that was shown at Open Day at the AEI Potsdam-Golm and IdeenExpo in Hannover [16], and a model of the LISA satellites that was shown on the Science Express, an exhibition train that had over 260,000 visitors [16].

Models of various LIGO parts have been created for museum and traveling exhibits. Riles assisted Daniel Holz at University of Chicago in creating an interferometer exhibit for display at the Adler Planetarious [39]. Grant and van Veggel have been four demonstration Michelson interferometer for outreach purposes, two of which are used by the Glasgow group for outreach events, one of which is for the Science Centre in Glasgow, and the last of which is for public events such as Glasgow Science Week [17]. Other items include an aLIGO test suspension rig and a GEO sapphire test mass contributed to the "Cosmos and Culture" exhibition at the Science Museum, London [16].

Science Museums and Planetariums

Groups have made efforts to support science museums and science centers, promoting gravitational wave science through these channels.

Parkinson and Yoshida proposed the addition of activities to exhibits at the Hammond Children's Discovery museum that relate to wave science, including activities that teach the concepts of period and frequency [33]. Farr, Rodriguez, and Raymond led the "Astronomy Conversations" program with the public on numerous Friday afternoons at the Space Visualization LAb of the Adler Planetarium and Astronomy Museum in Chicago, IL. These were in the format of conversations, with group sizes ranging from 20 to upwards of 60, and discussion topics given by visitors' questions. They have developed visual materials for these conversations which can be found on the DCC [26].

The Gravity Discovery Centre in Western Australia has completed a new slinky exhibit with assistance from LIGO members [46].

Riles served on the Ann Arbor Hands On Museum Board of Trustees [39].

10.3.6 Print Media

Development of Brochures and Leaflets

The "WSF 2010 Promotional Brochure" was produced for the World Science Festival by the Columbia group, and is available for viewing at `https://dcc.ligo.org/cgibin/private/DocDB/ShowDocument?docid=10249` [12].

The Sonoma [30] team developed and produced LIGO and LSC stickers in a NASA style to enhance the visibility of our projects through well proven ways.

The SSU group has produced postcards that advertise Einstein@Home and its connection to the use of Fermi mission data to look for gamma-ray pulsars. If you would like to distribute these postcards, please send mail to at `mailto:lynnc@universe.sonoma.edu` `Lynn Cominsky`, and indicate the quantity and postal mail address for shipping.

Promoting In-Fiction Placement of our Field

Material Development for Printed Media, Newspapers, Magazines, and Others

NASA's Space Place newspaper published an article on LIGO research to be distributed across the U.S. [40] In magazines, there have been numerous articles promoting LIGO and gravitational wave astronomy, which include one in the German popular astronomy magazine Sterne und Weltraum (Stars and Universe) [16], contributions to the Ultima Hora Column titled "Neutrinos con prisa" and "Al acecho de la particula divina" [5], an article in the Winter Magazine of the Spanish Astronomy Society [5], an article for an online magazine of the University of Valencia titled "Einstein en concierto" [5], and the article "Exploring the birth and death of black holes and other creatures" in the Annals of the New York Academy of Sciences [12]. In addition, members of the CCRG have been profiled in the Research at RIT magazine [28].

Supervising Science Summaries

Cavaglia proposed and initiated the "Science Summary" program of the LSC, which has since been set up by Shawhan on the ligo.org website. Cavaglia, Dietz, and Read [40], Lynn Cominsky [30] and Capano and Shawhan [38] have contributed to writing and editing science summaries [30, 38, 40].

Publishing LSC Newsletter and Magazine

The first issue of LIGO Magazine [6] has been published in September 2012, with feature articles and many fascinating pictures about the installation of the Advanced LIGO detectors. Currently this issue is only available online (as a pdf file) but already the download statistics from the webserver indicate an interest goes beyond our community with more than 1600 downloads, clearly dominating the server's bandwidth.

10.3.7 Performance Art

"Einstein's Cosmic Messengers" Solo Performance

"Einstein's Cosmic Messengers" is a multimedia concert production created by Andrea Centazzo. Concerts were given on Feb 5 and 6, 2009 at the University of Mississippi, Oxford, MS, and on March 13, 2010 at Northwestern. The latter was attended by more than 100 people, including the NU provost and people from the broader Evanston/Chicago area [26]. More information on this concert can be found at http://www.andreacentazzo.com/ecm, and a "making of" documentary feature is available on YouTube. Point of contact: Michele Vallisneri, Marco Cavaglia.

"Astrophysics and Dance"

The "Astrophysics and Dance" project uses dance and multimedia theatre techniques to reach a broad audience, about half of which is comprised of deaf and hard-of-hearing students. Joining artists and educators in the Department of Creative Studies and Arts of the RIT's National Technical Institute for the Deaf, Campanelli and Bischof have produced an aesthetic educational performance representing gravitational waves and the collision of black holes [28].

Spoken Word

"Music of the Spheres" is a multimedia talk on gravitational radiation and gravitational wave detection that combines film clips, images, and music with the spoken word and real interactive experiments. The talk has been given four times since its premiere, and is now even available with Chinese subtitles, which were used when the talk was given at Beijing Planetarium in May 2010 [16].

10.3.8 Up Close and Personal: Meet the Scientists

Interviews with LSC Scientists

The website http://www.scienceface.org presents a series of short films that include interviews with Joan Centrella, Gunter Hasinger, Kip Thorne, Cliff Will, and many other well-known scientists. The first series of thirteen film clips are available on the website, and a second series about gravitational wave research has been developed. Ten of these film clips have been translated into German [16].

Other LSC scientists have given interviews on TV, radio, and newspaper, including Carles Bona who was interviewed about the theory of general relativity on Radio Nacional, Zsolt Frei who has given radio and newspaper interviews about gravitational wave science, and a TV interview to members of the UIB group shown here: http://www.youtube.com/watch?v=GAilAbyhcG4 [5, 14].

"Travels of an Astrophysicist" Project

Blogs By LSC Scientists

Guided Tours

In September 2011, the Leibniz University Hannover opened its doors to high school students, inviting them to get an up-close impression of different fields of study and research. AEI provided these students with overview talks and guided tours [16].

In Hungary, there is a tradition called the "Night of Researces", during which many university laboratories invite the public to enter their labs and learn about the research that is being done. Eotvos is a regular participant of this event, providing a well-attended public presentation last September [14].

10.3.9 Expanding Our Audience

Engaging through Social Media: Facebook, Twitter, and Others

This past year Cavaglia managed the LIGO Twitter account on behalf of the collaboration [40]. Groups in the collaboration have also maintained their own Twitter accounts, using them for outreach purposes and to attract students to the field. These include http://twitter.com/uibgrg and http://twitter.com/#\mskip-\thinmuskip/ILCnewsline which operate under the @LIGO Twitter subgroup [5, 6, 41]. These have attracted hundreds of followers, including science journalists and science associations.

Cavaglia has also managed the LIGO Facebook acccount, recently converting the LIGO Facebook "User" to "Page" and maintaining regular status updates. This page has attracted over 400 "likes", in addition to the 74 on the UIB Facebook page [5, 40].

Multilingual Efforts: Web, Translations, Foreign Tweets, and Others

The film Einstein's Messengers has been translated into French using an English transcript. Both transcripts are available at http://www.andrews.edu/~tzs/EPO/ [4].

Translations of other materials have been made, including: the game "Black Hole Hunter" that is available in Spanish [5] and the game "Space Time Quest" [6] has been translated to Spanish, Catalan, Dutch and Chinese and the related gwoptics.com e-book on gravitational waves is now available in German, Italian, Spanish, Catalan, and Chinese [6].

Interfacing to LSC Diversity Group

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.

In 2012, the LSC formed a Diversity subcommittee, chaired by Marco Cavaglia. This subcommittee now has its own white paper, and has begun to prioritize tasks for future work. The major

outcome to date has been the unanimous adoption of a Diversity pledge by the LSC, which was highlighted at a diversity reception during the Spring 2013 LVC meeting in Maryland.

Any LSC members or groups interested in helping with this effort, should contact `lsc-diversity@ligo.org`.

Recruitment

LSC members have had extensive participation in the National Society of Black Physicists and Hispanic Physicists: Marco Cavaglia, Fred Raab, Jonah Kanner, Teviet Creighton, and Gabriela Gonzalez have given presentations at meetings [24, 38, 40]. In addition, members of Fullerton and San Jose State have attended and manned booths at SACNAS conferences (scientists dedicated to advancing Hispanics/Chicanos and Native Americans in science) [15, 29].

UTB had recruiting booths at the 2012 Society of Advancement of Chicanos and Native Americans in Science (SACNAS) National Conference held in Seattle and the 2012 Joint Fall Meeting of the Texas Section of APS, the Texas Section of AAPT and SPS held in Lubbock, Texas. Visitors to the booths were engaged in discussions about gravitational wave astronomy [43].

New Websites

The Science Education Enrichment Project Web Page was developed by University of Western Australia, a Spanish outreach page was created by University of Balearic Islands, and the ligo.org site has been maintained to accommodate Spanish translations and science summaries/outreach abstracts of LSC papers [5, 27, 46].

10.3.10 Other

"Engaging Young Minds" Project

10.4 EPO Professional Outreach Initiative Scope

10.4.1 Internal Education

Teach LIGO to LSC members and Other Professionals

Members of the LSC community have put much time and effort into educating each other about LIGO. L. Matone created and taught a 1-week intense course on control theory and digital signal processing. This class was designed to bring up to speed operators, graduate students and post-docs involved in the installation and commissioning of advanced LIGO. About 40-50 people attended the course at the two LIGO detector sites in the summer of 2011. The class had enthusiastic positive comments from participants, and Matone was invited again for a similar training course at the LIGO sites for the summer of 2012 [12]. Rollins visited Budapest for an extended period to help the ELTE group get acquainted with the Omega Pipeline for data analysis [12].

Efforts to reach out to fellow researchers who work outside the field of gravitational wave physics were undertaken by Kipp Cannon and Chad Hanna who created a gravitational wave themed presentation to display on the Perimeter's video wall [10]. Along the same lines, I. Bartos and Z. Marka gave presentations on LIGO research at AstroFest, an annual Columbia conference dedicated to sharing the best aspects of research by Columbians [12]. Members of the Eotvos group organized the 2009 LVC Meeting in Budapest, Hungary, where Ray Weiss gave a talk to the Hungarian physics community [14].

Teach the Art of Funding

Outreach Abstracts

Teach Effective Communication

Interface to LSC entities: WebCom, P&P, LAAC, and Others

Dictionary & Handbook Project

10.4.2 For Broader Scientific Community

APS, AAS, AAAS, IEEE, OSA, and others

The following are some highlights of LSC members participating in conferences that are not specifically focused on gravitational physics:

Overview of LIGO/Virgo Multimessenger Programs, AMON Workshop, Penn State University, October, 2011 [12]

Exploring the Birth and Death of Black Holes, INCREASE Workshop, BNL, April 2012 [12]

Cavaglia initiated and coordinated LIGO's participation to the 2nd USA Science and Engineering Festival in Washington D.C., April 2012. He staffed the LIGO booth with Martin Hendry (Glasgow), Peter Shawhan (UMD) and Dennis Ugolini (Trinity) and graduate students from UMD. LIGO's booth fee was covered through UMiss' NSF award. [40]

M. Cavaglia, Education and public outreach of the Laser Interferometer Gravitational-wave Observatory, Talk at the Meeting of the Division of Particles and Fields of the American Physical Society, Providence, RI, Aug. 9, 2011, LIGO Document G1100870-v1 [40]

Talk at the U.K. IOP High Energy Physics meeting, Queen Mary College, London, April 2012, on gravitational wave searches.

Talks at various astronomical society and 'SciBar' science interest groups on The Hunt for Gravitationl Waves. [42]

Facilitate Employment, Recruitments, and Conferences

Professional Tutorials through Web, Radio, WebCasts, PodCasts

GWIC

Milde Science Communication developed an internet portal about gravitational wave research that was approved to be a Gravitational Wave International Committee (GWIC) portal. As an introduction to the field, it informs about the science, the international collaboration, technologies, the multimessenger approach etc. and links to related websites. [16]

10.4.3 For Amateur Scientists

Distribution of Environmental Data; Enable Access and Use

Engage, Excite, and Facilitate Amateur and Citizen Science

Significant part of astronomy is being done by amateur astronomers. Many of them are highly educated serious researchers. Einstein@Home has already proved that there is tremendous interest in providing private resources for our studies. It also proved that there is coding talent who is willing to contribute. It took astronomy many years to foster and develop strong base of reliable and serious amateur astronomers. It might be an interesting exercise to devise a system where we raise amateurs who will volunteer and contribute on a useful and efficient way. For example there are many excellent programmers out there; they can help with coding, code review, and making our software faster, slimmer, and more reliable. There are trained science writers out there who might be interested in helping. I think if we search we will find a lot of high quality volunteer help. What can be better outreach than conveying the excitement through sharing the fun? For more information contact: Szabi Marka

Facilitate Crowd Sourcing

10.4.4 For General Public

Printed/Broadcast Media

Highlight Spinoff Tech

Development of Professional Exhibits

10.4.5 Other

Enable and Facilitate Industrial and Corporate Relations

A book has been completed and pulished on the LIGO coating thermal noise, aimed at scientists and engineers outside the field of gravitational wave detection [3].

Facilitate/Provide Science Interpretation for Policy Making

Cavaglia participated to a meeting with the staff of U.S. Senator Roger Wicker's (R-MS) staff on Nov 18, 2011. A poster describing the LIGO project and UMiss' role in the LSC was presented [40].

10.4.6 Case Study: Astronomy's New Messengers - An Exhibit for the General Public

One of the recent and ongoing 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 [64] 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 [65] through grant NSF-0852870 [66] 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 [67], a multi-disciplinary firm of architects, designers, and educators providing award-winning architecture and exhibit design services. Leni Schwendinger Light Projects [68], 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 **??** and **??**, 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 **??** and a large LCD screen with a looping high-quality video, originally produced by Milde Marketing [69] for the International Year of Astronomy [70] cornerstone project "100 Hours of Astronomy", deliver key informational points (Figure **??**, left.)

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 [71] kiosk. A second LCD screen with looping video compiled of clips from the NSF movie *Einstein's Messengers* [72] 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 [73] 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 setup. 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 **??**, 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 **??**.)

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 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 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 consists 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.

The floorplan of the larger *Astronomy's New Messengers* exhibit is illustrated in Fig. **??**. The exhibit is modular and self-contained. It requires an unimpeded area of 25' × 40' ($\sim$ 7.6 m × $\sim$ 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.

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 been put again on display in the lobby of the University Center at Shawnee State University (Portsmouth OH).

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 were certainly big hits, 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.

Other exhibitions

ImagineRIT

Every year the Center for Computational Relativity and Gravitation (CCRG) RIT showcases their work at the ImagineRIT festival [74]. 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.

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. In January 2013 this exhibit also featured in the BBC Stargazing LIVE event co-organised by the University of Glasgow, Glasgow Science Centre and BBC Scotland at Glasgow's Botanical Gardens.

- 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 has developed their own exhibition called 'Looking for black holes with lasers' which was first featured at the British Festival of Science in Birmingham in September 2010. The exhibit consisting of hands-on activities, such as a Michelson interferometers, and interactive computer games was attended by several thousand visitors and was very popular. The exhibit has since been shown at the Institute of Physics stand at the Big Bang Fair, a national science and engineering fair, in 2012 and was also used in a joint event with the Birmingham particle physics group during the national science & engineering week in March 2013.

- 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.

10.4.7 Case Study: Multimedia and interactive games by gwoptics.org

In 2010 the gravitational wave group at the University of Birmingham created a new and unique online platform to provide and distribute information, media and software tools for teaching and public outreach related to gravitational waves. The idea is to provide in one place fun activities, information about GW science and access to the real software tools that are used for designing GW detectors. Desktop computers, laptops and free software nowadays provide everyone with a fascinating and immensely powerful toolbox to learn and participate in science. The gwoptics.org page is meant to engage especially young people with science and to motivate them to use software as their "sonic screwdriver" for testing it out. The key components of our web presence are: Space Time Quest and Black Hole Pong, two computer games developed by the University of Birmingham group, that are free to download as stand-alone applications on Windows, Linux and Mac, see 17. Carbone et al. 'Computer-games for gravitational wave science outreach: Black Hole Pong and Space Time Quest', J. Phys.: Conf. Ser. 363 012057.

"Black Hole Pong": (BHP www.gwoptics.org/bhp/) is an arcade-style game, a re-edition of the classical game Pong, with black holes and stars in place of paddles and a ball. The game delivers an intuitive feeling for the gravitational potential and the graphics and control via Xbox-controllers were designed to attract games-aware children. BHP is a simple fun activity to catch the attention using the elements of gravity and black holes. "Space Time Quest" instead is a manager-simulation game in which the player designs a future GW detector, making choices about instrument systems, such as the laser power, size and type of optical components or the pressure in the vacuum system. The game uses an accurate noise model of GW detectors and represents a very realistic insight into one of our main research topics. However it has been designed to be a fun activity rather than overly educational, featuring high quality, cartoon-style graphics and an online "hall of fame".

"GW Ebook": A short selection of texts written by students introducing gravitational waves and the various topics of GW detector design. The Ebook can be used as a complementary information package for the game Space Time Quest or as a basic introduction to the research topic of gravitational wave detection itself. The text is self contained and provides links to other activities on the page.

Processing and Scratch interactive Simulations: Processing and Scratch are free and open programming environments dedicated at teaching the use of computer algorithms outside computer science. Both originate from the MIT Media Labs, with Scratch being dedicated at young children and Processing at artists and designers. Both can be ideal tools to engage people of all ages, who did not have any previous experience with code or programming, with the concept of software as an easy and fascinating tool to learn, to create and to investigate. The page www.gwoptics.org/processing/ hosts powerful, visual interactive exhibits that pick up single topics linked to instrument research, such as the functioning of a laser, or the motion of a pendulum, and investigate these in a simple interactive simulation. This form of exhibit was used to catch the attention of children who are well used to the "iPhone-experience", using a carefully chosen mix of games, simple animations and real simulations. All these activities are open and free, the source code is provided online, inviting people to download and tinker with the scientists' work.

`Finesse` and Simtools: One step away from the games and simple interactive simulations is `Finesse`, see Freise et al "Frequency-domain interferometer simulation with higher-order spatial modes" CQG 21 (2004), one of the main interferometer simulations in the field. `Finesse` is free and open source; it has been developed to assist the development and operation of large-scale laser interferometers for GW detection, but it is designed as a general-purpose optics simulation and is supported by many online examples, an extensive manual and related open-access research publications. This makes it a great tool for students to explore the field of laser optics, engaging with actual and current research.

Evidence for Impact Online: The efforts to create something new and unique have been recognized early and a review by Physics World in 2011 concludes: "*This is different to most research-group websites [...] Kudos to the Birmingham group for doing something more interesting here.*" The statistics extracted from the webserver logfiles show a steady and fast increase in visitors to www.gwoptics.org since its launch, with currently an average of 140 unique visitors per day and more than 100,000 page impressions per month. Furthermore Google currently counts more than 1000 incoming links to the gwoptics webpage. In addition to links from the main GW related sites, most of the incoming links are from popular science pages and from web sites dedicated to the learning and teaching of programming. This is a strong sign for the wide appeal of our activities and indicates that especially our interactive Processing online apps are of interest to popular science outreach as well as to people learning to program. The impact of our web presence can be shown through the development of the audience over time.

The Birmingham group has recently also developed a complementary site to gwoptics, `www.sr.bham.ac.uk/gwastr` which aims to introduce Gravitational Wave Astrophysics at a late high school / undergraduate level. It includes animations, created by the group, of CBC waveforms and data analysis techniques. The website will be expanded to allow members of the collaboration and the public to create their own animations. The website also contains the rates calculator which calculates the number of GW CBC detections that would be made, dependent on the specific choice of instrument and cosmology.

Download statistics related to Space Time Quest and the GW Ebook are good performance measures.

These elements can be considered as ideal performance indicators as they have been created recently by the Birmingham group, are unique to the GW community and provide the most direct link between online games, using computers as a creative tool and the research for GW detectors. Within one year from its first release almost 10,000 downloads of Space Time Quest had been recorded. The online high-scores table for STQ shows over 5000 entries, proving that the game is actually played through by a large fraction of people who downloaded it (online high scores are only created when the game play is fully completed while the computer is online). The monthly views of the GW Ebook show a mostly steady increase over time, with peaks of 3000 visitors per month to that part of the gwoptics page only. It can be seen that the interest in these activities is boosted by events, such as releases of new material online, or by promoting gravitational waves at science fairs.

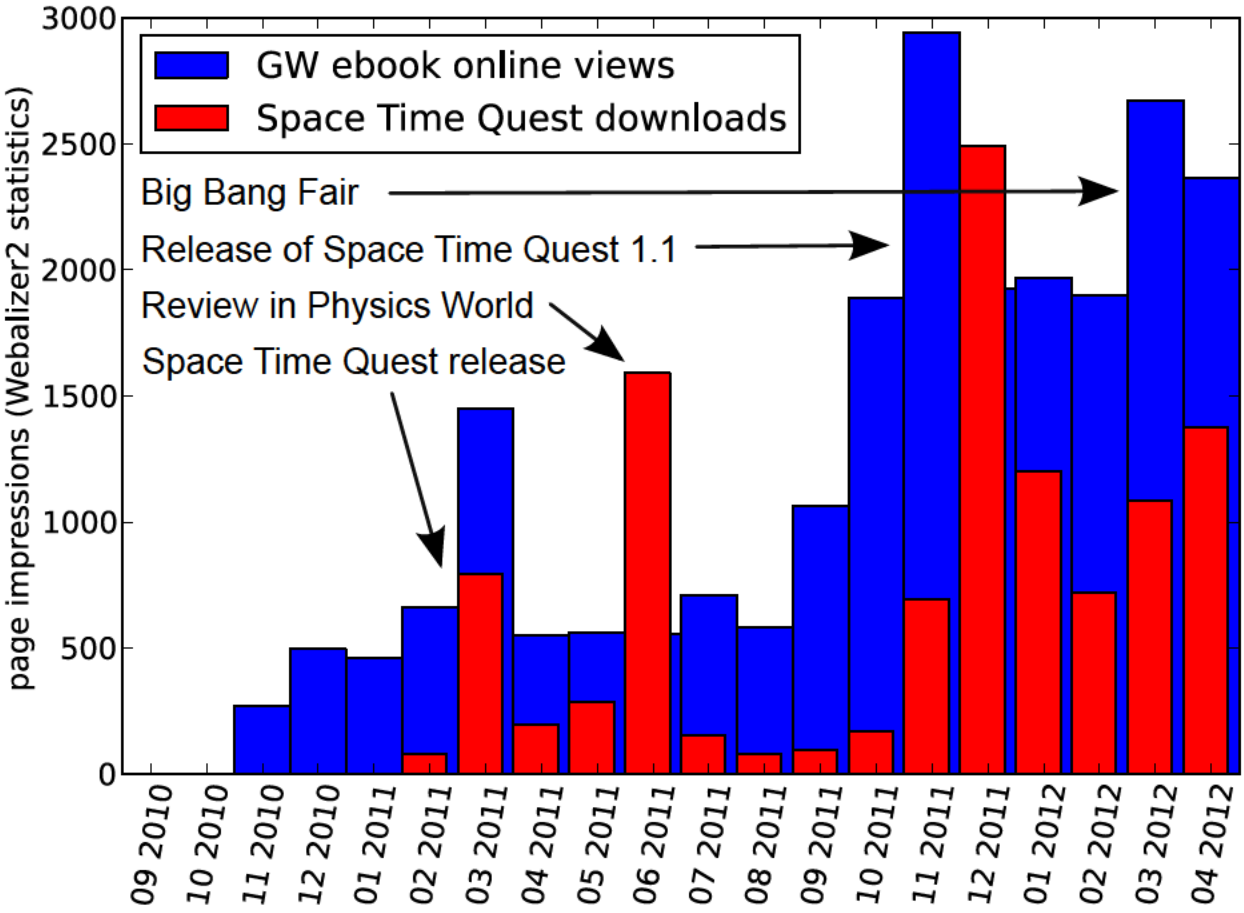

Figure 10.3: Download statistics related to Space Time Quest and the GW Ebook are good performance measures.

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