The LSC White Paper on Communications, Education and Public Outreach

Goals, Status and Plans, Priorities (2020-2021)

Communications and Education Division of the LSC[1]

July 27, 2020

[1]EPO E-mail: lsc-epo@ligo.org, EPO Wiki: http://wiki.ligo.org/EPO, and CEPO White Paper Internal Version in DCC: https://dcc.ligo.org/T2000425

1 Executive Summary and List of Priorities

This document presents an Executive Summary of the priorities and objectives for 2020-21 of the Communications and Education Division of the LIGO Scientific Collaboration; they are also set out in Section 2.10 of the LSC 2020-21 Program. Broader context for these priorities is provided in the subsequent chapters. LSC Groups are encouraged to consult this Executive Summary, and the associated table of activities and tasks[1], when formulating their 2020-21 MoU plans. Groups are also welcome to contact the C&E Division Chair or relevant member(s) of the EPO Committee to discuss their plans. (See 1.4 for names and contact details.)

1.1 Communications and Education Division: Mission and Goals

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; the LSC believes that the opportunity to discover the beauty of the cosmos should not be limited by age, culture or abode.

The LSC EPO working group was established in 2008 and aims to lead the LSC efforts to carry out this mission. In 2020, following a comprehensive review of LSC structures and organisation, the EPO working group was re-designated and re-organised as the Communications and Education (C&E) Division of the LSC.

By combining and synthesising a range of ideas and approaches across participating institutions, and promoting collaboration and sharing of best practise, the LSC C&E Division seeks to communicate LSC science and to create education and outreach programs which are far more effective than they would be if LSC member institutions worked independently.

The C&E Division's program of activities and priorities is shaped by the following general goals:

- To communicate LSC results in an accessible way to the world - to other physicists, students, and the general public.
- To develop educational resources that will inspire and train the next generation of scientists and build overall scientific literacy.
- To advocate for future development and growth in our field, in partnership with LSC/Lab leadership and the broader GW and EM astronomy communities.

[1] available on google sheets here. Note, ligo.org login credentials required.

1.2 EPO Priorities for 2020-21

1.2.1 Priorities for the LIGO Laboratory

The current priority areas for LIGO Laboratory Outreach are as follows:

1. We will expand the LIGO Livingston Observatory (LLO) Science Education Center (SEC) capability for evaluating the impact it has on students participating in field trips, continuing to serve the local teacher community through summer workshops and collaborative teacher exchanges. The 2020 summer teacher workshops will be held virtually.

2. We will continue work to develop the LIGO Exploration Center (LExC) at the LIGO Hanford Observatory (LHO), for which $7.7M was approved by Washington State for design and construction planned for 2021.

3. We will continue to organize a yearly International Physics and Astronomy Educator Program at LHO. This Program will be held remotely in 2020.

4. We will continue to work with collaborators from across astronomy to produce a multi-messenger astronomy masterclass.

5. We will change our virtual offerings, primarily targeting local schools with virtual tours and classroom oriented experiences in order to help deal with the current pandemic.

1.2.2 Priorities in Formal and Higher Education

The current priority areas for Formal and Higher Education are as follows:

1. We will develop new classroom units for high schools aligned with Next Generation Science Standards (NGSS) and other appropriate international school standards, including updates and revisions of existing classroom activities.

2. We will develop high-school teacher training materials that can be tested and evaluated prior to use.

3. We will conduct professional development with high school teachers at local, regional, national, and international venues.

4. We will develop new classroom and laboratory activities on LIGO-related data analysis, astrophysics, and experimental topics, suitable for use in high school and undergraduate introductory astronomy and physics classes.

5. We will help to promote the Gravitational-Wave Open Science Center, in order to encourage and facilitate the use of the public strain data and other analysis data products that are curated there by the public, in educational settings, and by professional scientists.

1.2.3 Priorities in Informal Education and Public Outreach

The current priority areas for Informal Education and Public Outreach are as follows:

1. We will maintain, update and renovate the ligo.org website for informal users.

2. We will continue worldwide outreach and communication through social media (Twitter, Facebook, Instagram, Reddit) and other informal educational materials that showcase our observational and instrument science and the importance of multi-messenger astronomy.

3. We will provide educational materials and social media support for exceptional event announcements.

4. We will continue answering question@ligo.org queries, developing efficient approaches to curate and organize them.

5. Together with Virgo and KAGRA, we will develop printed material and multilingual resources including science summaries for collaboration papers.

6. We will promote development of innovative approaches that communicate LIGO science, such as audio, video, virtual reality, web and phone apps, video games and planetarium shows.

7. We will develop and maintain tools to share, in low latency, public alerts of detection candidates and resources to explain the content of these alerts.

8. We will explore innovative approaches to generating and disseminating this content that will be scalable to the candidate event rates expected for O4.

9. We will support the Humans of LIGO blog, Gravity Spy and other relevant citizen science initiatives.

10. We will support our LSC members communicating our science through public talks, writing popular articles, and communications on social media such as Twitter, Reddit or blogs.

11. We will develop and curate a bank of approved graphics and multimedia on all aspects of gravitational wave science, suitable for LSC, Virgo, and KAGRA colleagues to use in public lectures.

12. We will support LSC presence at major science festivals, exhibitions, and other high-profile public events that attract large audiences both online and face-to-face.

13. We will develop flexible and easily portable resources that can be used at exhibitions as well as other informal education and outreach events.

1.2.4 Priorities for Professional Outreach

The current priority areas for Professional Outreach are as follows:

1. We will maintain, update and renovate the ligo.org website for professional scientists.
2. We will support the provision of information and materials for professional astronomers, including public alerts during observing time, organization and promotion of LVK webinars, and communication with the astronomy community as described in the Operations Analysis white paper.
3. We will promote outreach to scientists and policy makers at professional conferences and meetings, both online and face-to-face, working in collaboration with other gravitational wave communities where appropriate.
4. We will develop flexible and easily portable resources that can be used at professional conferences and exhibitions as well as other informal education and outreach events.
5. We will aim to enable our collaboration members to present the science of our latest results at conferences in talks and panel discussions, through online presentations, and at seminars and colloquiums at individual institutions.
6. We will help to promote the Gravitational-Wave Open Science Center, in order to encourage and facilitate the use of the public strain data and other analysis data products that are curated there by the public, in educational settings, and by professional scientists.

1.2.5 Priorities for Public Relations and Communications

The current priority areas for Public Relations and Communications are as follows:

1. We will continue to support communication with media contacts and to provide media guidance and training for collaboration members.
2. We will coordinate regular communication liaison for LVK public announcement of scientific results, particularly (but not only) O3 exceptional event papers and webinars.
3. We will develop a framework (appropriate both for O3b and for the event rates anticipated in O4) for deciding when LSC papers are worthy of public announcement, as e.g. exceptional events and/or webinars, and for effective and efficient management of these public announcements.
4. We will maintain and produce public materials such as the LIGO Magazine.

1.3 EPO Committee: Present and Future

The EPO Committee is defined in the Bylaws 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 the Chair's 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."

As of July 2020, the EPO Committee comprises:

- Martin Hendry (EPO Chair: martin.hendry@ligo.org)
- Amber Stuver (Informal Education & Public Outreach Lead: amber.stuver@ligo.org)
- Amber Strunk (Formal & Higher Education Lead, and EPO Lead for LIGO Hanford: amber.strunk@ligo-wa.caltech.edu)
- William Katzman (EPO Lead for LIGO Livingston: wkatzman@ligo-la.caltech.edu)
- Marc Favata (WebComm Chair: marc.favata@ligo.org)

Following re-organisation of the EPO working group and its re-designation as the Communications and Education Division, during 2020-21 the EPO Committee will similarly be re-designated and re-organised to include representation from the Chairs (to be appointed) of the C&E Division Committees. These Committees are:

- Formal Education Committee
- Informal Education and Public Outreach Committee
- Professional Outreach Committee
- LSC Web Committee
- Media Relations Committee
- LIGO Magazine Committee

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2 Introduction

2.1 Our EPO Philosophy

This White Paper outlines the 2020-21 priorities for the (erstwhile) Education and Public Outreach (EPO) committee[1] of the LIGO Scientific Collaboration (LSC). It also provides a description and summary of current efforts and elaborates on the goals, philosophy, and plans of our international network of scientists. It is not meant to be a comprehensive list or to contain the history of all LSC EPO efforts. This is a living document that is updated regularly and is improved continuously.

More than half of the research groups in the LSC 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.

The goal of the LSC is the detection of gravitational waves from cataclysmic astrophysical sources. The first direct measurements of gravitational waves has opened 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.

LSC outreach initiatives seek to inform the public not only about the exciting new 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, materials science, computing facilities and data acquisition. The cornerstones of this program are the following principles:

- 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 is revealed by non-electromagnetic means through the detection of gravitational waves. Mapping the gravitational-wave sky provides an understanding of the Universe in a way that electromagnetic observations cannot.
- 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

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vacuum technology, precision lasers, measuring techniques, and advanced optical and mechanical systems is required to observe gravitational waves.

2.2 EPO Aims and Objectives

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 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.

2.2.1 EPO Aims

The broad outreach aims of the LSC include:

- Communicating the scientific activities and discoveries of the collaboration through national and international news media, as the field of gravitational-wave astronomy becomes firmly established in the mainstream of astronomical research;
- 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;
- Improving understanding by the citizenry of frontier science and large scientific projects.

2.2.2 EPO Objectives

The EPO Group seeks to achieve these aims by focussing our efforts on the following objectives:

- To build upon the tremendous global coverage and excitement associated with the discovery announcements to date (building upon the extraordinary level of public interest in the GW150914 announcement) and the dawn of gravitational-wave astronomy
- To arouse interest, attention, and motivation for outreach activities across the collaboration;
- To ensure that collaboration skills are optimally used to enhance the collaboration's public visibility;

- To coordinate the EPO activities of the LSC and wherever possible to align them closely with those of our Virgo and Kgara colleagues;
- To streamline and optimize the development and use of EPO resources;
- To create, facilitate, and nourish synergies among teams within and outside of the LSC;
- To interface EPO needs, goals, and objectives to the practical realities (e.g., prioritization, resource management, external hooks, etc.).

2.3 Scope of our EPO Activities and Programs

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

- Organisation of press and media events to announce gravitational-wave discoveries;
- Events at the observatory outreach centers, on-site and online 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 social media;
- 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.

Our EPO 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.

LSC outreach efforts should continuously explore new opportunities to promote science among adolescents and young people. LSC 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 and communication skills.

3 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 nearby institutions and outreach interests. After years of steady growth in the breadth of outreach activities and in the strength of regional partnerships, LIGO's site-based programs reached over 30,000 people in 2015. Each observatory aims to thoughtfully serve the large underrepresented populations that reside in the nearby counties/parishes.

LIGO Livingston's Science Education Center (SEC) now represents 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. LIGO Hanford's, soon to be constructed, LIGO Exploration Center (LExC) is poised to follow suit in Washington State region.

3.1 Overview

Staff (5.25 FTE) are responsible for operating the outreach programs at the observatories. 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. Normally, the vast majority of Hanford and Livingston outreach contacts are face-to-face – although the COVID-19 pandemic has drastically changed this pattern in spring summer 2020. Additional site-based interactions occur with visitors who connect to the observatories via Zoom 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 observatories to bear on these projects as needed. Technical and outreach staff in the Lab collaborate with members of the LSC EPO group in promoting LIGO to the public and to diverse student groups through participation in conferences and exhibitions. Activity also flows into the Lab through the LSC EPO group as personnel at LSC locations are able to connect their local constituents with education resources that are available through the observatories.

3.2 LIGO Livingston Observatory and the LIGO Science Education Center

3.2.1 Past and Current Activities

In 2004, a successful proposal to the NSF authored by a partnership of LIGO, Southern University at Baton Rouge (SUBR), the Exploratorium, and the Louisiana Systemic Initiative Program and Louisiana GEAR UP resulted in the construction of the 10,000 sq. ft. Science Education Center (SEC) at the Livingston site. The SEC currently houses over 50 Exploratorium-style exhibits that focus on the science themes of LIGO. Auditorium and classroom space near the exhibit hall 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. This year the SEC served 2787 on-site K-12 visitors and trained 200 K-12 teachers and pre-service teachers through teacher workshops. Since its inception, the SEC has seen an increase in LLO's on-site outreach attendance from 1100 on-site visitors in 2004 to around 12,000 on-site visitors in 2015. In this past year, in spite of the pandemic, LIGO-SEC was able to reach out to approximately 7843 individuals.

3.2.2 Needs and Future Plans

The Science Education Center (SEC) at the LIGO Livingston Observatory has transitioned to a regional collaboration headed by the Baton Rouge Area Foundation (BRAF). 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 LIGO/SUBR (Southern University of Baton Rouge) docent program. This program involves SUBR STEEM (Science, Technology, Engineering, Education, Mathematics) students who are trained in interacting with the school children and the general public around LIGO-based themes. This program is intended to provide effective role modeling for visitors, while at the same time instill a passion for science outreach in the undergraduates.

Another aspect of this mission involves prioritizing local partnerships that will yield more teacher professional development opportunities targeted at local teachers. Teachers then spend time at LIGO's Science Education Center, where physical science concepts are explored as they relate to the overall LIGO project.

In the future the SEC will need to retain the ability to involve LIGO in new and innovative outreach work as such opportunities arise, while at the same time serving its core audiences.

- We will expand the Science Education Center (SEC) capability for evaluating the impact it has on students participating in field trips, continuing to serve the local teacher community through summer workshops and collaborative teacher exchanges. The 2020 summer teacher workshops will be held virtually.

- We will change our virtual offerings, primarily targeting local schools with virtual tours and classroom oriented experiences in order to help deal with the current pandemic.

3.3 LIGO Hanford Observatory

3.3.1 Past and Current Activities

LIGO Hanford (LHO) created a full-time outreach coordinator (EOC) in 2004 and the individual who holds this position manages LHO's outreach program. The site maintains 10 interactive exhibits to support school field trips and family-oriented outreach activities. The EOC and past summer teacher interns have developed a number of portable hands-on physics interactives for use in schools and in community venues. LIGO's participation in the QuarkNet program 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 2016, just after the first detection announcement, LHO's outreach contacts peaked at 21,464, roughly 8,570 of these contacts where through onsite field trips, public tours and public events. The overwhelming interest in LHO's outreach programs was unsustainable for the facilities and level of staffing at that time and contacts were reduced in subsequent years.

Current outreach efforts are focused on the construction of the LIGO Exploration Center (LExC). In 2019 LExC was funded by a $7.7 M grant from the State of Washington through the Office of Superintendent of Public Instruction. LExC will be an approximately 13,000 sq. ft. outreach center. The selection of the design-build team in 2020 was a major step forward in this project. Construction is set to be completed by the end of 2021. Additionally LHO has hired a second full time staff member. Both efforts will increase the ability of LHO to meet the needs of its local community and return to 2016 outreach levels.

3.3.2 Needs and Future Plans

Space limitations at the LIGO Hanford Observatory had, in the past, placed a cap on the number of interactive exhibits that the site could host. The funding and construction of LExC will allow for growth of the exhibit collection. Continued efforts will focus on obtaining the additional funding necessary to furnish and run the facility.

The Advanced LIGO and Virgo discoveries, along with the 2017 Nobel Prize have created a swell of interest in LHO's outreach programs; every effort should be made to maintain the outreach momentum that the discoveries have created. To capitalize on some of the unique findings of these discoveries it is important for staff to work with collaborators around the world and across astronomy to produce new and exciting outreach activities and materials.

- We will continue working to develop the future LIGO Exploration Center, for which $7.7M has been approved by Washington State for design and construction in 2019-2021.
- We will continue to organize a yearly International Physics and Astronomy Educator Program at LIGO Hanford. This Program will be held remotely in 2020.

- We will continue to work with collaborators from across astronomy to produce a multi-messenger astronomy masterclass.

4 Formal Education

Traditionally, formal education is conducted in schools by classroom teachers, for students in grades K-12 (or their equivalent in other countries and regions). 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.

The COVID-19 pandemic has caused many formal educational activities to move to virtual delivery. While this has introduced significant short-term problems, particularly in relation to practical teaching, it has also created new opportunities for innovation – for example broadening the geographical reach of activities or allowing the straightforward creation of legacy archived materials – many of which may prove useful and sustainable even when face-to-face activities resume more regularly.

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 new era of GW astronomy has provided an unprecedented opportunity to engage hundreds of thousands of students nation-wide and internationally in deeper learning. To this end, we have created an educator's guide to accompany and explain GW detections, and have conducted workshops with teachers to train them to use these materials in the classroom.

4.1 Formal Education Unit Inspired by LIGO

The discovery of gravitational waves was (and continues to be) big news - and teachers across the country want to quickly understand the physics and astronomy behind these exciting, new phenomena. Although a quick educator's guide that explains the initial discovery of gravitational waves was produced by the Sonoma State University team on behalf of the LVC, and was published online in February 2016, it was not subjected to classroom testing or external evaluation. There remains a need for standards-aligned and well-tested materials that can be used at different grade levels. This type of effort will require significant funding and the development cycle for a well-tested guide will take approximately 3 years.

The Next Generation Science Standards present a coherent way of doing science in K-12 classrooms that is based on three interwoven strands: Disciplinary Core Ideas (DCIs), Science and Engineering Practices, and Cross-Cutting Concepts. The DCIs a most relevant to LIGO are the High School Physical Science including: PS2: Motion and Stability: Forces and Interactions; PS3: Energy; and PS4: Waves and Their Applications in Technologies for Information Transfer. Additional connections to LIGO science include DCIs in High School Earth and Space Sciences in: ESS1: Earth's Place in the

Universe and connections to LIGO technology can be made through High School Engineering Design (ETS1-4). As part of PS3, students are asked to demonstrate their understanding of engineering principles when they design, build, and refine devices associated with the conversion of energy. An interferometer may be an example of this type of energy conversion.

The High School Physical Science DCIs include Newtonian gravitational forces, as well as electromagnetic waves and their properties. These are common content standards also found in the older National Science Education Standards (from the National Science Teachers Association) and also in the AAAS Project 2061 Benchmarks that are still in use in most states. 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 NGSS also stress the connections between scientific ideas and the engineering practices needed to conduct the scientific inquiry. For example LIGO and Virgo instrumentation is a prime example of how students could demonstrate their understanding of engineering ideas by presenting information about how technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. Again, the development of LIGO and Virgo 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.

4.2 Teacher Professional Development Related to LIGO

At the present time, both LIGO Observatories (Hanford and Livingston) conduct teacher professional development programs. LIGO Livingston Observatory (LLO) averages about 200-300 teacher contacts each year, while LIGO Hanford Observatory (LHO) averages about 75. 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 per year to over ten thousand students per 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.

Over the years LIGO Hanford has hosted many different professional development opportunities both at the observatory and in conjunction with local educational partners. Currently LIGO Hanford conducts 2-4 hour to day long workshops with partners each year as well as hosting The International Physics and Astronomy (IPA) program for educators. IPA is a week long, intensive, program for high school physics, astronomy, and mathematics teachers. Through lectures, hands-on activities, and tours teachers are exposed to the basics of LIGO, nucleosynthesis, EM astronomy, and the new era of multi-messenger astronomy. The opportunity to be immersed, with teachers from around the world, in current scientific research with the scientists and engineers who are making that science happen provides a lasting impact on teachers.

LLO's outreach in formal education resembles the Hanford program in its aims and objectives but differs somewhat in its methods. Grant-funded projects known as Math Science Partnerships (MSPs) often use LLO and its Science Education Center (SEC) as an extended field trip and learning opportunity, while CORE Element & MS State's IMPACT program typically utilize LIGO's resources for two day educational excursions. Meanwhile, Southern University Baton Rouge conducts a week-long

LIGO-related professional development opportunities funded through the NSF with significant interaction at LLO's Science Education Center. Recent external evaluation of the professional development conducted by LLO has concluded that "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." To answer that call, Southern University did create a leadership track, attempting to create "teacher leaders" out of teachers who were previously LLO-trained.
In the past LLO and LHO both have hosted summer teacher interns through NSF's Research Experience for Teachers (RET) extension of the Research Experiences for Undergraduates (REU) program (LIGO Lab has been a REU site for years). Currently the RET component is absent from LIGO's REU award and the observatories are using other means to host summer teachers. LIGO Hanford currently serves as a host site for the STEM Teacher and Researcher program (STAR) that is operated by Cal Poly San Luis Obispo.

Teacher internships represent a powerful tool in LIGO's efforts in formal education. These experiences provide teachers with authentic research opportunities and the chance to develop relationships with scientists and engineers, outcomes that can transform teachers' views of science and engineering practices. Teachers also work on the integration of their summer experience into their classroom teaching, producing lesson plans and other materials that LIGO can incorporate into its larger teacher professional development programs.

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 possible method to fund this work is by writing an RET supplement for your existing NSF REU award.

Professional Development for LIGO should adhere closely to the ideas in "Designing Professional Development for Teachers of Science and Mathematics" by Loucks-Horsley et al. 2010.

Organizing Teacher Professional Development Workshops

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 American Association of Physics Teachers,
- 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 – as do many other countries around the world. 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 are an effective way to reach many students. Additional leverage is gained by developing teacher training materials for use by LSC members at a wider variety of local training events. All teacher training materials should be made publicly available through the LIGO website. Best practices for organizing teacher training events include:

- workshop is free or provides a stipend for attendance
- provide free classroom materials that are aligned to local standards
- align workshop with a specific strand that is being organized by the national society to increase the odds that the workshop proposal will be accepted
- workshop should model best practices in formal education, with an appropriate balance between lecture and hands-on activities
- work with an expert in education to ensure that the LIGO science is translated appropriately for the classroom

4.2.1 On-line Teacher Professional Development

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

Best practices for developing on-line teacher PD include:

- minimal cost for teachers to participate
- academic or continuing education credits must be offered
- a wide variety of resource materials should be developed and previously classroom-tested ? evaluation of pre- and post-teacher knowledge should be conducted
- teachers should produce a lesson plan for their classrooms as their summative experience

4.3 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. EPO has been in contact with APS regarding a new issue of their comic book that includes LIGO. Help is needed to develop these ideas, and to provide input into a middle-school kit of experiments that could be distributed through Physics Quest.

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."

Additional existing resources that can be modified and updated to align with the NGSS include the classroom activities and demos that have been developed by Penn State and other members of the LIGO project. They can be accessed from the ligo.org site. Effort is required to adapt the I2U2 and Penn State materials to align with NGSS.

Developing curriculum for the formal education system is a major undertaking, that 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 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 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 websites.

Additional sites that feature excellent resources for the classroom include:

- Teacher's Domain
- NSTA Learning Center
- NASA Wavelength repository of classroom materials
- What Works Clearinghouse, US Department of Education repository of professionally evaluated materials

4.4 Gravitational Wave 'Master Class' for High School Students

The concept of developing a GW master class has been suggested several years ago by Nicolas Arnaud, following the model used in particle physics. Originally designed for high school students to teach about the LHC, a GW-oriented master class would consist of lectures, a data analysis activity, Q&A sessions and a concluding videoconference session that reaches many geographically-separated sites.

The idea of creating a masterclass, focussed on presenting the scientific potential and excitement of gravitational-wave astrophysics and/or multi-messenger astrophysics to high school audiences, has advanced significantly in the past year and is now a key priority for the EPO group. This has been driven firstly by direct and highly positive interactions with the International Particle Physics Outreach Group, which has illustrated the potential for such an approach, and then gained further impetus from the creation of an International Gravitational-Wave Outreach Group – as developed following the iGrav satellite meeting held after the Amaldi gravitational-wave conference in Valencia, July 2019. (The 2020 annual iGrav meeting will take place virtually in July 2020, having originally been planned as a satellite meeting of the 2020 LISA Symposium in Glasgow before that meeting was cancelled due to COVID-19). EPO Colleagues are strongly encouraged to get involved with the iGrav initiative.

4.5 The Einstein First project

Another significant recent development in Formal Education is the 'Einstein First' project, a global collaboration in physics education in which LSC members, led by Ozgrav colleagues, play a major role. This project seeks to teach the fundamental concepts of modern physics to school students and works to improve STEM involvement in the classroom. Through the project, core funding for which is provided by a major award from the Australian Research Council, researchers in astrophysics and education are investigating the ability of schoolchildren to understand Einsteinian physics through class intervention and teacher education. The project also explores family education and public outreach.

The Einstein-First Project currently works with school students from Year 4 to Year 12 within Western Australia. It is slowly expanding to other states within Australia and is working with researchers from around the world. An Einstein First collaboration meeting was held in Perth, WA in early 2020. More information about the Einstein First project can be found here.

4.6 Dissemination of Formal Education Products

At the present time, the main dissemination mechanism for LSC Formal Education Products is through the LIGO website. The LIGO Educator's Guide, and links to other resources can be found on this site. Effort is required to publicize these materials, as well as the Science Summaries in order to increase the dissemination of all developed products.

4.7 Formal and Higher Education Priorities

Below is the list of 2020-21 Formal and Higher Education priorities for the EPO group (further context for our Higher Education priorities are given in Chapter 5):

- We will develop new classroom units for high schools aligned with Next Generation Science Standards (NGSS) and other appropriate international school standards, including updates and revisions of existing classroom activities.
- We will develop high-school teacher training materials that can be tested and evaluated prior to use.
- We will conduct professional development with high school teachers at local, regional, national, and international venues.
- We will develop new classroom and laboratory activities on LIGO-related data analysis, astrophysics, and experimental topics, suitable for use in high school and undergraduate introductory astronomy and physics classes.

- We will help to promote the Gravitational-Wave Open Science Center, in order to encourage and facilitate the use of the public strain data and other analysis data products that are curated there by the public, in educational settings, and by professional scientists.

5 Higher Education

Higher education is conducted in community colleges and universities by faculty and via online settings. EPO group work related to higher education includes the creation of well-tested classroom materials, as well as training the faculty who will deliver these materials. It also includes direct work with college students in classroom settings, and research opportunities for students.

The COVID-19 pandemic has caused many (indeed most) higher educational activities round the world to move online. While this has introduced significant short-term problems, particularly in relation to practical teaching, it has also created new opportunities for innovation – for example broadening the geographical reach of activities or allowing the straightforward creation of legacy archived materials – many of which may prove useful and sustainable even when face-to-face activities resume more regularly.

Many of the activities created by LSC members for use with senior high school students are appropriate for use by lower division college students. Others are more sophisticated, and are better aimed at STEM majors who can be expected to have more sophisticated mathematics skills. To achieve the highest leverage, EPO should aim new curriculum development activities at two distinct populations: Astro 101 students and lower-division engineering physics majors. Approximately 250,000 students take Astronomy 101 (often called "Descriptive Astronomy") each year, and for most this is the only college science course that they will take.

Aiming exciting LIGO-inspired materials at this population provides an opportunity to persuade students to consider a STEM major, especially if their interest is captured in their first year in college. Lower-division calculus- based physics courses (often called "engineering physics") is taken by approximately 10% of all college students. An additional avenue is the development of laboratory exercises that could be used in either Astronomy lab classes, or in upper division physics labs. Infusing LIGO-related science and technology into these courses is another natural avenue to widen our reach.

5.1 In Person Faculty Professional Development Related to LIGO

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

5.2 On-line Teacher Professional Development

Best practices for developing on-line faculty PD include:

- minimal cost for faculty to participate
- academic or continuing education credits are offered
- a wide variety of resource materials should be developed and previously classroom-tested
- evaluation of pre- and post-teacher knowledge should be conducted

5.3 Resources for College Faculty

Creating and maintaining a comprehensive list of resources about LIGO that is appropriate for college faculty is a priority for EPO. In recent years the Sonoma State University E/PO group has developed two online courses for instructors of lower-division, calculus-based physics courses. The 2015 course *LIGO: Waves and Gravity* included three new units of material: Learning more about Light; Geometry and Gravity of Weak Fields; and Astrophysics of Compact Sources. To view the 2015 course: https://universe.sonoma.edu/moodle/course/view.php?id=2

The 2016 course *LIGO: Detecting Gravitational Waves* included five new units of material: Introduction and Background; Direct Observations; LIGO: The Basic Idea; Sources of Noise; and Signal Extraction. To view the 2016 course: https://universe.sonoma.edu/moodle/course/view.php?id=3

The Gravitational-Wave Open Science Center hosts an entire series of video tutorials about how to use the LIGO and Virgo data, following several "Open Data Workshops" that have been held since 2018 (including an entirely online workshop, in spring 2020). The videos and other useful information can be found here. These tutorials may be a good starting point for creating new workshops specifically designed to train college faculty.

A new LIGO-oriented resource list should be included as part of the update of the ligo.org website.

It is also important to create physics applets and other online interactive activities that feature LIGO science and/or technology. Examples from physics and astronomy include:

- Java-based applets at the University of Birmingham, UK
- physlets at the University of Colorado
- Astronomy Flash interactives at the University of Nebraska, Lincoln
- Chirp, an app developed at the University of Birmingham, UK, to support open LIGO-Virgo public alerts.

After classroom testing, new LIGO activities and resources should be submitted for inclusion in sites such as:

- ComPADRE Digital Library
- MERLOT
- National Science Digital Library

5.4 Resources for College Students

Although it will require considerable resources for LIGO to create an entire one-semester course specifically about LIGO, it may be possible to create individual units which may be used to supplement existing Astronomy 101 or lower-division physics courses. Research-oriented institutions may also be able to offer an entire course as a "Special Topics" course for upper division physics majors.

These types of courses may achieve wider success if offered as online or hybrid curricula, and should be extensively tested in the classroom, and thoroughly evaluated before being offered to the wider community. Due to the large numbers of Astronomy 101 students, it may be more effective to develop new activities for this mathematically-challenged population. Revising the existing Penn State materials would be useful to create units that can be used in physics or astronomy classes.

The Gravitational Wave Physics and Astronomy Center at the California State University, Fullerton has developed a quiz for gravitational wave astrophysics, a series of lecture slides, space-time curvature demos, and several think-pair-share questions for introducing ASTR 101 students to gravitational-wave astronomy, based partially on interviews and tests of GWPAC undergraduate and Masters research students.

The Sonoma State group has developed a two-semester curriculum in astronomy and cosmology for general education college students, which is now being distributed by Great River Learning. For more information, see greatriverlearning.com/Cosmology.

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 that uses the edX platform.

Beyond the First Year laboratory classes are typically taught to undergraduate (and occasionally graduate) physics majors and constitute a significant amount of the preparation in experimental physics that graduating physics majors (and hence entering graduate students) receive.

Much experimental physics is currently done using computers to analyze data collected by large experiments like LIGO, but there are limited opportunities to acquaint students with this form of experimental work.

A laboratory project using LIGO open data should be developed by LSC members to used in a Beyond the First Year laboratory class. This lab project can be made available both to other LSC groups and the wider physics community (perhaps through a LIGO master class for high school students) to improve laboratory classes and student preparation, expose students to data analysis as an experimental physics technique, and make LIGO data analysis techniques more widely known in the physics community.

Marc Favata is leading a collaboration with ThorLabs with the objective to help the company develop education lab kits related to LIGO science. A discussion of LIGO has been added to the manual (and website) of their upcoming interferometer kit. We are hoping that they will develop additional kits that we could contribute to in more detail. In particular, (i) a low-cost model IFO ($500 or less, suitable for high schools or younger) and (ii) a more advanced IFO kit than their upcoming model–perhaps with Fabry-Perot cavities or other elements–suitable for an advanced university physics course. In connection with this effort, Dennis Ugolini recently published an American Journal of Physics article discussing a range of undergraduate labs relevant to gravitational-wave interferometry.

5.5 Talks and Lectures

Perhaps one of the easiest ways to reach college students is via physics or astronomy colloquia at community colleges and universities. The creation of a LIGO Speaker's Bureau section with volunteers who are expert in reaching public audiences would be a great addition to the LSC.

The American Physical Society maintains a Women Speakers List and all female LSC members are encouraged to sign up to represent LIGO topics. Similarly, the APS maintains a Minority Speakers List and also offers travel grants of up to $500 to the participating institution to support invited minority lecturers. The American Astronomical Society sponsors the Harley Shaplow Lectureships and any LSC member with an interest in the more astronomically-related LIGO subjects should consider applying for this program.

5.6 Summer Research Programs

Authentic research experiences in LSC-groups provide an important introduction to disciplinary socialization, which has been shown to be a key factor in the retention of (especially under-represented) students in STEM majors (Clewell et al. 2005). Proven examples include:

- Research Experiences for Undergraduates (REU) programs that are routinely offered at several LSC member sites, including: the University of Florida, University of Texas Rio Grande Valley, Louisiana State University,
- CalTech's SURF (Summer Undergraduate Research Fellowships) program
- Sonoma State University's Global Telescope Network which provides free access to both northern and southern telescopes for student use to observe LIGO-related astronomical objects

The University of Florida's REU program operates internationally: this program encourages participating American students to learn about the growing internationalization of research and to establish scientific contacts beyond the borders of the United States. Students intern at gravitational wave research facilities in Australia, Europe and Asia as part of this program. Effort is required to collect examples of LIGO-related summer research projects that could be featured on the LIGO website. We also encourage LSC groups to include student internship activities, especially for students that are under-represented in STEM.

5.7 Formal and Higher Education Priorities

Below is the list of 2020-21 Formal and Higher Education priorities for the EPO group (further context for our Formal Education priorities is given in Chapter 4):

- We will develop new classroom units for high schools aligned with Next Generation Science Standards (NGSS) and other appropriate international school standards, including updates and revisions of existing classroom activities.

- We will develop high-school teacher training materials that can be tested and evaluated prior to use.
- We will conduct professional development with high school teachers at local, regional, national, and international venues.
- We will develop new classroom and laboratory activities on LIGO-related data analysis, astrophysics, and experimental topics, suitable for use in high school and undergraduate introductory astronomy and physics classes.
- We will help to promote the Gravitational-Wave Open Science Center, in order to encourage and facilitate the use of the public strain data and other analysis data products that are curated there by the public, in educational settings, and by professional scientists.

6 Informal Education and Public Outreach

Informal education refers to content-rich activities that are conducted outside of formal education programs (e.g. high school or college) and involves engagement with informal learners of all ages – sometimes through brief and stand-alone interactions, although also frequently through ongoing and repeated engagement.

For the LSC, these informal education activities span a very broad range in scope – from local initiatives that engage LSC staff and students in delivering informal talks and workshops to astronomy societies and science festivals, to coordinated global activities such as the citizen science program GravitySpy and social media in support of our public alerts.

Informal education also includes after-school programs, web-based activities, and exhibits at science museums. This section of the white paper also provides context for our public outreach such as social media, mainstream media (press releases and conferences) and materials developed for distribution to the general public e.g. via large public lectures and other events.

The COVID-19 pandemic has caused many informal educational and outreach activities to move to virtual delivery. While this has introduced significant short-term problems, it has also created new opportunities for innovation – for example broadening the geographical reach of activities or allowing the straightforward creation of legacy archived materials – many of which may prove useful and sustainable even when face-to-face activities resume more regularly.

6.1 Visual Media

As the Detection Era proceeds, it is vital that the LSC continues to develop and improve its suite of visual media clips that can be used by mainstream and online media. The resources assembled for the detection announcements to date can be found on the detection pages for individual events at ligo.org/detections.php and on the EPO wiki. Areas where additional resources are needed include:

- more animations of detected, or likely upcoming, GW events – especially NS-NS and NS-BH events, BH-BH mergers, bursts, supernovae, continuous waves, cosmic strings, and other results from numerical simulations
- animations and video footage relevant to EM-follow up of GW events, e.g. explaining how we localize GW sources on the sky
- overview shots of the observatories
- diverse scientists working on various types of hardware

- interesting shots of the hardware systems,

Ideally these should be available in various resolutions, including HD and 30 second length for use by mainstream media, about 2 minutes of narrated stories for YouTube audiences and to be used in press releases, and additional "B-roll" to support media releases. Press choose snippets of B-roll to talk over in news reports.

Best practices in this area include NASA's Scientific Visualization Studio which is a repository of all the visual media developed to support NASA press conferences. Note the many different formats and lengths of animations plus still images available for each release. The LSC and LIGO Lab has already excelled in creating longer explanatory videos such as Einstein's Messengers, Kai Staats' films, including LIGO: A Passion for Understanding, LIGO: Generations, LIGO: Detection and the Advanced LIGO Documentary project by Les Guthman.

The LSC and Virgo Collaboration have their own YouTube channel, and contributions to this channel are greatly encouraged. Assistance with curating this channel is also sought.

6.2 Web Media

The power of the internet to reach a wide audience is almost immeasurable. We should continue relations with established comics such as PhD Comics, HowToons, TED-Ed, Spectra comics from APS and animated comics such as the PhD Comics Higgs Boson Explained and encourage them to continue to feature LIGO in their offerings.

Additional opportunities for web media promotion include talsk at events such as TEDx: an independently organized TED event. These events can achieve extremely high profile and impact and are becoming increasingly common in other fields of science. 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 in the LSC Document Control Center (DCC).

Our LIGO Virgo YouTube channel is also curating educational multimedia, including much of the content produced for the GW150914 and subsequent detections and a number of public lectures, TEDx talks and other public events delivered by LVC scientists. YouTube has also been successful at disseminating discovery announcements as evidenced by the live streaming of e.g. the GW170817 press conference.

More generally, the web traffic generated to our sites has shown a significant and sustained increased since the first detections, and has prompted the EPO group to consider carefully how best to maintain up-to-date, visually attractive and relevant web content on www.ligo.org, with only limited LSC resources currently available to assist with this task. We welcome dedicated effort from across the LSC to help with this, via liaison with the Web Committee Chair.

6.3 Audio Media

With the Detection Era well underway, it is also extremely important to continue to curate a collection of the best audio clips that convey the "sound" of gravitational waves corresponding to the first detections and other sources that are likely to be detected in the future. Examples for the detections to date can be found on the EPO wiki – and the audio files for GW150914 in particular have been consistently featured prominently in the media coverage. The Gravitational Wave Open Science Center now features audio files of all confirmed detections – including those reported in our O1-O2 gravitational-wave catalog, GWTC-1, published in December 2018 and the "Exceptional Events" already published from O3. You can find these audio files here.

The group at Montclair State University has created Soundsofspacetime.org to explore the "sonification" of GW signals, giving intuition on the effects of changing different physical parameters. This website is a resource for the general public, undergrads or other students learning about GWs, and scientists looking for sounds to use in talks or other instruction. The site covers a range of different kinds of binaries, and includes separate pages for several LIGO detections. In the near term the site will be expanded to include all recent detections and a larger variety of source types (beyond binaries). A companion iOS/Android app is also in development (see also Section 6.6 below).

6.4 Multimedia

Previously the LSC supported the highly successful Einstein's Cosmic Messengers multimedia concert, conceived by renowned musician and composer Andrea Centazzo and LSC member Michele Vallisneri. The Celebrating Einstein art+science materials including the Black (W)hole art installation and the A Shout Across Time multimedia performance have been hosted by LSC institutions Montana State University, the University of Texas Rio Grande Valley, and MIT.

Additional instructive examples include Kip Thorne's work on Interstellar (for which the LIGO scenes were cut) and its popular book The Science of Interstellar. Another notable example is the A Capella Science video LIGO Feel That Space; indeed several of the videos produced by A Capella Science are outstanding examples of multimedia science communication that combine education with novelty and entertainment. Any ideas that colleagues have for similar future collaborations and performances are very welcome.

6.5 Social Media

Social Media accounts maintained by the LSC include Facebook (LIGO Scientific Collaboration), Twitter (@ligo), and Instagram (ligo_virgo). It is widely recognized that these social media platforms made a major contribution to the enormous global media impact of the GW150914 detection announcement - with huge growth in the number of followers and 'likes' for Twitter and Facebook respectively at that time.

LSC EPO members are strongly encouraged to contribute to the team posting on these pages, as a steady flow of updates is essential to continue to build the audiences for each. This has been particularly important throughout O3, where our social media platforms were used to rapidly share information about our public alerts – and will be even more important in O4.

As of June 2020, LIGO had $>$ 30K followers on Facebook, $\sim$ 103K followers on Twitter and (LIGO-Virgo) had $\sim$ 8K followers on Instagram. Despite their enormous and sustained growth since early 2016 (prior to the GW150914 detection announcement @LIGO had less than three thousand followers) these audiences could be much larger still. For example, even in 2015 @NASAFermi had over 41K followers on Twitter, Space Telescope had over 28,000 “likes” on Facebook, and CERN had over 1.25 million Twitter followers for @CERN and over 468,000 Facebook fans.

In particular there is opportunity to make further impact through social media by increasing utilization of Instagram. All posts to this social media outlet require an image attachment. The EPO team welcomes any offers of help with any of our social media accounts.

LSC members who have content that they would like to be posted to the LSC’s Twitter, Facebook, or Instagram (Instagram needs an accompanying image) accounts should send news and related items to social.media@ligo.org.

Reddit is another web platform that is being very effectively utilized by the LSC. The Reddit AMA (Ask Me Anything) forums organized in February 2016, June 2016, and October 2017 were an enormous success. Involvement by LSC EPO members in future AMA and related activities (e.g. Google hangouts) is strongly encouraged.

The most widely read LSC scientist blog is Living LIGO by Amber Stuver from Villanova. Although it is not an official LIGO publication, it offers clear explanations of questions of interest to the LIGO-attentive public, as well as personalizing the LIGO project. Other example blogs are written by Christopher Berry and Shane Larson. All are excellent examples of individual efforts that have an impact that greatly exceeds its cost, and similar efforts by a diverse set of LSC scientists are greatly encouraged.

The “Humans of LIGO” blog (https://humansofligo.blogspot.com/) is a recent endeavor that profiles an LSC member with a photo, biographical information, and some other information such as facts or quotes. The aim of this effort is to humanize LIGO science and the people who do it. The project was launched in summer 2018 and has been posting profiles regularly ever since. Additional, similar work includes the outstanding video series at scienceface.org which highlight a wide range of aspects of gravitational-wave science via extended interviews with leading members of the GW community.

As well as maintaining individual blog sites on the web, members of the LSC EPO group periodically monitor other blog and internet traffic, looking out for stories or comments relevant to gravitational wave science (particularly those which are overtly critical towards or misrepresent our field). While some such blog comments emanate from ‘fringe’ sources and are not worth engaging, 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 about LIGO science.

Following the GW150914 detection announcement, the EPO group set up a dedicated email address (question@ligo.org) to coordinate responses to inquiries from the general public. There have been hundreds of questions posted and feedback from the questioners has been very positive. The EPO group welcomes the help of more LSC members to assist with these activities – particularly helping to respond promptly and constructively to question@ligo.org inquiries.

Finally, following the detection announcements there has been significantly increased activity on LIGO-related Wikipedia pages, including pages specifically generated to describe GW150914 but also pages that existed before that describe the LIGO project and the LSC. While Wikipedia protocol dictates that these pages should not be maintained by members of the LSC, there is no issue with LSC members monitoring - and where appropriate editing - Wikipedia pages. The EPO group would greatly welcome colleagues willing to assist with this task.

6.6 Apps and Software Tools, Computer and Board Games

The LSC has already created several computer games and apps. Especially notable are the suite of apps, interactive web activities, and software tools from the Birmingham group via their LaserLabs and gwoptics website. These include:

- Chirp, an app developed at the University of Birmingham, UK, to support open LIGO-Virgo public alerts.
- Black Hole Master (formerly Black Hole Pong): an arcade-style re-imagining of the classical game Pong, with black holes and stars in place of paddles and a ball.
- Pocket Black Hole: uses the phone or computer camera to demonstrate live gravitational lensing near a black hole.
- Stretch and Squash: illustrates the deformation from a gravitational wave on a static image or camera feed.
- Space-Time Quest: a game about designing and optimizing a gravitational-wave detector.
- 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 as documented by Freise et al "Frequency-domain interferometer simulation with higher-order spatial modes" CQG 21 (2004), one of the main interferometer simulations in the field.
- A self-study course on Laser Interferometry based on IPhython notebooks.

Additional online games include the UK Cardiff group's Black Hole Hunter.

Best practises for future game development include: a) needs assessment for target audiences, b) development on modern platforms to ensure portability and sustainability, and c) comprehensive user testing and feedback prior to release.

There has also been significant progress in developing apps and sky visualization tools in support of GW astronomy - for example the Chirp app mentioned above, and the gravoscope software developed at Cardiff that allows GW sky localization information to be overlaid on top of EM astronomical survey data. Other instructive examples include the LHC Android App, and sky visualization tools such as Google Sky and Microsoft's World Wide Telescope.

Another excellent example of online tools is the 'virtual tour' of the LIGO observatory developed by the LSC group at the Eotvos University in Hungary. The Montclair State University group is also developing an iOS and Android companion app to the soundsofspacetime.org. The app will allow users to manipulate the parameters of a gravitational-wave source to produce the resulting waveforms and corresponding audio.

Another area that is developing rapidly is the use of Virtual Reality. With the advent of Google Cardboard, VR has become available to anyone with a smartphone. It may be possible to adapt the state-of-the-art software used to design LIGO to produce the 3-D visualization files needed to run on VR platforms. One example is the VR movie developed by Within and MIT, The Possible: Listening to the Universe. Other work in this area is being done by Dawn Garcia, Jamie Rollins, and others, who are proposing a low-cost VR exhibit entitled "Space Waves."

VR content is also a major part of the Ozgrav EPO activities, and has produced some outstanding examples of gravitational-wave related VR content; for more information visit the SCIVR website.

Rollins has also developed Observe! - a board game based on the quest to detect gravitational waves. Two or more players compete to detect the most gravitational waves by hiring scientists and engineers, researching detector technology, and building the most sensitive ground-based interferometric gravitational-wave detector. Players must balance detector upgrades and observing runs so as to maximize their detection potential, and be the first to detect the elusive gravitational wave. It is in beta-test and is available from here: https://gitlab.com/jrollins/ligo-game

6.7 Citizen Science

Gravity Spy is an established (in October 2016) and very successful LSC collaboration with the Zooniverse citizen science team to develop a LIGO Glitch Zoo project. There are tremendous opportunities for engagement with the wider public via this project, building upon our prior experience with Einstein@Home. LSC groups are particularly encouraged to get involved.

Einstein@Home remains one of the best examples of citizen science today and was developed by the former LSC group in Hannover. Originally designed to search for gravitational wave signals during personal computer idle time, the software has discovered more than 50 new radio and gamma-ray pulsars to date in data from the Arecibo radio telescope and NASA's Fermi Gamma-ray Space Telescope.

Another recent project to reach citizen scientists is Gravoscope, developed by the Cardiff group. Gravoscope combines two distinct views of the Universe. You can explore our Galaxy (the Milky Way) and the distant Universe in a range of wavelengths from gamma-rays to the longest radio waves, and overlay the locations of detected GW events.

6.8 Exhibits

One of the most prominent pre-discovery achievements by the EPO group was the design, delivery and display of two NSF-funded exhibits, entitled 'Astronomy's New Messengers' showcasing gravitational wave science. These 'large' and 'small' exhibits have traveled around the US, with particular success at New York City's annual World Science Fair. Similar, smaller exhibitions have also been successfully displayed at various events, including annual attendance at the amateur astronomy event NEAF (NorthEast Astronomy Forum). Updating all exhibits to include information about LIGO's discoveries is a top priority.

Permanent museum exhibits are very costly (millions of dollars) and are typically about 5000 square feet. These types of exhibits are usually developed by the museums in situ. Traveling museum exhibits, while also expensive, are typically 1000 square feet, and can reach much wider audiences as they travel around the country. This is the size of the larger version of 'Astronomy's New Messengers.'

The smaller version (about 200 square feet) proved to be very versatile, and the development of additional and updated similarly sized exhibits is a priority for future LSC EPO. Recently, the LSC has begun to use the smaller size of exhibit in booths at scientific and diversity conferences.

Conference booth sizes start at 10 x 10 feet and the LSC rented a double-wide booth (20 x 10 feet). Although booth rentals start at about $3500 for a 10 x 10 space, copies of this type of booth display are relatively inexpensive and could be created by LSC groups for use at local conferences. Many of the resources needed to create this type of exhibit are available on the EPO wiki as well as here. A typical exhibit booth could include:

- Pop-up LIGO and GW banners
- A portable backdrop on gravitational-wave astronomy
- A small table-top Michelson interferometer
- Computer displays or touch screens for showing multimedia and/or running games software, such as movies and animations on gravitational-wave astronomy (many links on the EPO wiki), Black Hole Hunter, and Black Hole Pong
- Handouts about LIGO science and technology, including flyers with science summaries
- 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 include a slinky to demonstrate fundamental wave properties, stretched rubber or lycra sheet to allow a simple demonstration of spacetime curvature, or an adaptation of Fermi’s “Make your own pulsar” activity with 2 inspiraling pulsars.

The COVID-19 pandemic has resulted in a number of conferences and science festivals moving online in 2020. There are good opportunities to develop innovative virtual exhibits and experiences, suitable for online use.

Thinktank Birmingham Science Museum exhibit

A museum exhibit piece has been designed, created, and installed at the Thinktank Birmingham Science Museum (Thinktank) in the UK by the University of Birmingham’s Institute for Gravitational Wave Astronomy. The Thinktank is Birmingham city’s science museum visited by families and school groups. The exhibit centres around a table-top Michelson interferometer and uses custom-built exhibit software to explain gravitational-wave detectors and sources through videos, animation, images, and text. Users can interact with the interferometer via buttons which produce simulated gravitational-wave signals by moving one of the interferometer mirrors. It was supported by the Science and Technology Facilities Council and the Royal Astronomical Society. The exhibit has been on long-term display at the Thinktank since 2016 and was included at the 2017 Royal Society Summer Science Exhibition, Listening to Einstein’s Universe. The LSC will support this project and the exhibit team in continuing to work in collaboration with the Thinktank museum staff to monitor reception and make improvements. A paper has been submitted on this project and a website publishes design specifications and instructions for others to build their own versions. .

6.9 Printed Materials

The LSC has produced a wide variety of printed materials that are aimed at various audiences. Especially notable examples are the LIGO Magazine and the LVC Science Summaries.

The LIGO Magazine, edited by the LIGO Magazine Editorial Team is an outstanding effort, and LVK EPO members are strongly encouraged to contribute to future issues. Issues have been published twice a year since 2012. It is a high visibility product with great accessibility by the general public and value within the LSC.

A significant 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. Dozens of LSC and Virgo members have written science summaries that are now posted on ligo.org. 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. Additional public friendly Science Summaries of LSC publications exist in both online and PDF flyer formats.

Participation by LSC EPO members in the creation, and translation, of new science summaries is a high priority activity – in particular those summaries associated with the suite of detection papers associated with "Exceptional Events" and other high-profile announcements. We also welcome suggestions for new ways (e.g. via email lists, arxiv.org, astrobites.com, or other online communities) for advertising and distributing these summaries to help maximize their impact.

In collaboration with the Contemporary Physics Education Project, Sonoma State University has created a poster entitled "Gravity: from Newton to Einstein." This poster is now sold by CPEP, which is a non-profit group. The Villanova group has also worked with the APS to create a freely distributed poster titled "Multimessenger Astronomy" which is a follow-up to the "Gravitational Waves".

6.10 Connections to Art, Theater, and Dance

At the March 2015 and March 2016 LVC meeting in Pasadena, attendees were treated to a display of art by Jim Barry, who illustrated many aspects of LIGO science with his imaginative creations. Many other artists and composers are now getting involved in gravitational wave creations:

- The National Youth Orchestra of Great Britain premiered a new piece inspired by gravitational waves on August 6, 2016.
- The March APS meeting Sing-a-Long featured the song "I'm a LIGO Believer"
- LIGO's detection announcement inspired the creation of an entry to the Eurovision contest by a contestant from Moldova

In recent years there have been several further examples of fruitful art-science collaborations:

- The LIGO Hanford Observatory has been partnering with the Mid-Columbia Ballet to teach dance and science to middle school students. The program includes various sessions with one of MCB's teaching artist, a tour of LIGO, Classroom visits and finally an event at LHO that includes displays of student created art and MCB dancers performing original dances inspired by LIGO on various tour stops.

- OzGrav researchers and outreach team have been working with a local artist who is creating a planetarium show called Particle / Wave. The focus on the show is on gravitational waves. Our group has provided text and digital animations for the show, which was featured as part of the 2018 Melbourne Festival, a major arts festival.

- Artist and musician Sarah Farmer has worked with the University of Birmingham Institute for Gravitational Wave Astronomy to develop a general relativity music ensemble with improvising musicians. The aim of this collaboration is to foster artistic experimentation and the exchange of knowledge between Sarah and the scientists within the gravitational wave group.

- In 2017 the Institute for Gravitational Research in Glasgow worked with the Glasgow Science Festival team on "Chasing the Waves": a comedy musical telling the history of the field that led to the first gravitational-wave detection. This award-winning musical has been performed to schools and public audiences of several thousand people.

- The Birmingham Institute for Gravitational Wave Astronomy is also working with sound artist Leon Trimble to exploit gravitational wave instrumentation to create sound. A portable Michelson interferometer has been built and is connected to a modular synthesiser via a solenoid and photodiode readout. The synthesiser can either be played live in a performance setting or interactively and is often accompanied by a public talk. There have been over 15 major performances, in the UK and abroad including BBC Digital Planet and TEDx. Leon has recently published The Gravity Synth EP and Gravity Synth tracks can also be found on Soundcloud.

- Two artists-in-residence with Swinburne University have collaborated with OzGrav scientists to create a new exhibit called DEEPER DARKER BRIGHTER. To quote... 'The exhibition offers an immersive and stimulating space wherein fresh awareness of the cosmos and science is mediated via aesthetic and conceptual means.' OzGrav outreach also supported the exhibit by providing VR demos to attendees of the art exhibit.

- The Astronomy Picture of the Day image for February 11th 2016 was the result of a fruitful collaboration with scientific illustrator Aurore Simonnet of the Sonoma State University group, and several other iconic images (e.g. of GW170817) have been produced by Aurore more recently. We encourage future science-art collaborations, particularly in the context of e.g. visually arresting posters and info-graphics that convey key information about the initial discoveries. Some excellent examples can be found on the EPO wiki.

- The LSC group at RIT has created Astrodance which tells the story of the search for gravitational waves. Astrodance combines dance, multi-media, sound and computer simulations to engage the audience in the understanding of science through artistic expression. The general public was also invited to discuss cutting-edge scientific questions with the scientists participating in the project.

Other notable examples of successful collaboration in this sphere include Dance Your PhD, and the innovative dance performance The Matter of Origins directed by Liz Lerman which explores the origins of matter and the mind's capacity to understand beginnings from the quantum to the cosmic scales. Although this area is not a priority, as time and talent permits LSC EPO members are encouraged to develop similarly creative endeavors.

6.11 Multilingual Outreach

International members of the LSC are active in translating LSC sources into their native languages. The primary effort has been on translating Science Summaries and Press Releases (especially for detection announcements). While we were formerly translating parts of ligo.org, we have moved away from direct translations and have begun using Google Translate. While imperfect, it allows the entire website to be translated automatically into nearly all languages. Future translation efforts would be most helpfully directed to materials that are specifically targeted to populations unlikely to speak English. This includes non-scientists and children.

6.12 Outreach to Children

Additional resources are needed to do effective outreach to children who are too young to comprehend the details of gravitational waves, but who are nonetheless intrigued by astrophysical objects such as black holes, etc. Many of the attendees at science festivals bring young children who can be engaged by activities such as:

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

LSC members have recently worked with the creators of the Spectra comic series to develop a special issue focused on LIGO and starring actual LSC members. Another possibility 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 or as a one-off outreach effort. A similar project being discussed is a Physics Quest kit for middle school students (see section 4.3). Recently, Mariela Masso Reid has written a pop-up children's book with colleagues in LIGO India, targeted to the communities where the LIGO India detector will be built.

6.13 Public lectures

Given the opportunity to hear from experts, the general public shows great interest and curiosity about the LIGO research program. These audiences are comprised of a wide range of members of the broader community, from children to retirees, including many people fascinated by advances in science but without easy access to experts. Many LIGO collaborators are active in presenting public lectures suitable for general audiences. The EPO encourages public lectures that communicate the latest public results of LIGO, the technical details of LIGO instrumentation, as well as the more general astrophysical context of the results. These efforts bring the science to populations not normally exposed to it, excite these populations about scientific advances, and generate further interest in LIGO and broader scientific endeavors. These lectures can also inspire young people to consider study and careers in scientific fields.

LSC members know their subject well, but need to translate the technical details into a language and presentable format comprehensible to general audiences. The education levels of such audiences may not include higher education, or even high school physics. EPO and others have developed tools essential to produce successful public lectures, with goals to inspire audiences to appreciate scientific progress and also to stimulate their interest in further investigations.

6.14 Priorities for Informal Education and Public Outreach

- We will maintain, update and renovate the ligo.org website for informal users.
- We will continue worldwide outreach and communication through social media (Twitter, Facebook, Instagram, Reddit) and other informal educational materials that showcase our observational and instrument science and the importance of multi-messenger astronomy.
- We will provide educational materials and social media support for exceptional event announcements.
- We will continue answering question@ligo.org queries, developing efficient approaches to curate and organize them.
- Together with Virgo and KAGRA, we will develop printed material and multilingual resources including science summaries for collaboration papers.
- We will promote development of innovative approaches that communicate LIGO science, such as audio, video, virtual reality, web and phone apps, video games and planetarium shows.
- We will develop and maintain tools to share, in low latency, public alerts of detection candidates and resources to explain the content of these alerts.
- We will explore innovative approaches to generating and disseminating this content that will be scalable to the candidate event rates expected for O4.
- We will support the Humans of LIGO blog, Gravity Spy and other relevant citizen science initiatives.
- We will support our LSC members communicating our science through public talks, writing popular articles, and communications on social media such as Twitter, Reddit or blogs.
- We will develop and curate a bank of approved graphics and multimedia on all aspects of gravitational wave science, suitable for LSC, Virgo, and KAGRA colleagues to use in public lectures.
- We will support LSC presence at major science festivals, exhibitions, and other high-profile public events that attract large audiences both online and face-to-face.
- We will develop flexible and easily portable resources that can be used at exhibitions as well as other informal education and outreach events.

Another priority for EPO is engagement with the professional astronomy community – via e.g. hosting exhibits or giving talks and organizing sessions and workshops at AAS or APS meetings. This is also covered in Chapter 7, but overlaps significantly with some of the activities showcased above. If colleagues are interested in helping with any of the above priority activities please contact lsc-epo@ligo.org.

7 Professional Outreach, Public Relations and Communications

Professional outreach, or *advocacy*, is a part of outreach and education that targets audiences that may or may not be literate in gravitational wave physics, but who can and do have influence on the professional evolution of the field. There are a variety of audiences for such professional outreach efforts. The goals of these activities are to engage with, to educate and to inform anyone whose role gives them the opportunity to interface with gravitational wave physics – either at the level of individual scientists and PIs engaged in gravitational wave research, or in policy making that may have bearing on the future of the field. These audiences include, but are not limited to:

- other scientists, particularly colleagues in the home departments of LSC groups, as well as scientists in fields that have the potential to overlap with gravitational wave physics (astronomy, optics, computational physics, etc.)
- the broader academic community, including university administration, as well as program officers at funding agencies and/or foundations
- government and legislative officials and staffers as well as other opinion leaders like journalists

LSC public relations and professional outreach activities are generally coordinated with the Virgo and Kagra collaborations. Examples of the scope and focus of our professional outreach include:

- organizing and participating in national and international conferences, and in online webinars, to disseminate the collaborations' scientific results;
- developing a communications strategy for promoting the scientific goals of the collaborations, and working with media professionals to publicize our discoveries and scientific results through press releases and press conferences;
- organizing workshops, parallel sessions and other special events (e.g. exhibitions) and sessions at national and international meetings;
- developing and promoting collaborative meetings and workshops between other scientists and gravitational-wave communities;
- encouraging broad-based professional engagement through giving colloquia and other presentations at universities and laboratories.

7.1 Priorities for Professional Outreach

- We will maintain, update and renovate the ligo.org website for professional scientists.
- We will support the provision of information and materials for professional astronomers, including public alerts during observing time, organization and promotion of LVK webinars, and communication with the astronomy community as described in the Operations Analysis white paper.
- We will promote outreach to scientists and policy makers at professional conferences and meetings, both online and face-to-face, working in collaboration with other gravitational wave communities where appropriate.
- We will develop flexible and easily portable resources that can be used at professional conferences and exhibitions as well as other informal education and outreach events.
- We will aim to enable our collaboration members to present the science of our latest results at conferences in talks and panel discussions, through online presentations, and at seminars and colloquiums at individual institutions.
- We will help to promote the Gravitational-Wave Open Science Center, in order to encourage and facilitate the use of the public strain data and other analysis data products that are curated there by the public, in educational settings, and by professional scientists.

7.2 Priorities for Public Relations and Communications

- We will continue to support communication with media contacts and to provide media guidance and training for collaboration members.
- We will coordinate regular communication liaison for LVK public announcement of scientific results, particularly (but not only) O3 exceptional event papers and webinars.
- We will develop a framework (appropriate both for O3b and for the event rates anticipated in O4) for deciding when LSC papers are worthy of public announcement, as e.g. exceptional events and/or webinars, and for effective and efficient management of these public announcements.
- We will maintain and produce public materials such as the LIGO Magazine.