# The LVK White Paper on Communications, Education and Public Outreach

**Goals, Status and Plans, Priorities**
**(July 2021 – December 2022)**

Prepared by the Communications and Education Division of the LSC[1]

Written in conjunction with the Education and Public Outreach Groups of the Virgo Collaboration and the KAGRA Scientific Collaboration.

July 30, 2021

[1]EPO E-mail: lsc-epo@ligo.org, EPO Wiki: http://wiki.ligo.org/EPO, and EPO White Paper Internal Version in DCC: https://dcc.ligo.org/LIGO-T2100307

# Executive Summary and List of Priorities

This document presents an Executive Summary of the priorities and objectives of the Communications and Education Division of the LIGO Scientific Collaboration – covering the period July 2021 to December 2022 and aligning with the 2021 edition of the LSC Program. Broader context for these priorities – including brief articles describing EPO activities, strategies and goals of the Virgo and KAGRA Collaborations, and how these are integrated into coherent LVK plans – is provided in the subsequent chapters. LSC Groups are encouraged to consult this Executive Summary, and the associated tables of activities and tasks[1], when formulating their 2021-22 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 below for names and contact details.)

## 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. The full structure of the new Division has yet to be fully implemented, and this is an over-arching goal for the Division over the first six months of the next MoU review period - i.e. before the end of 2021.

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.

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

- To advocate for future development and growth in our field, in partnership with LSC/Lab leadership and the broader GW and EM astronomy communities.

## EPO Priorities: July 2021 to December 2022

The following sections identify priority activities for the next 18 months, a period that will include the first months of Observing Run 4. The activities listed below are further broken down into detailed tasks, as summarized in google sheets available here.

### 1. Priorities for the LIGO Laboratory

Priority areas for LIGO Laboratory Outreach are as follows:

1. We will expand the 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 (including remote activities, where appropriate / required).
2. We will continue work to develop the LIGO Exploration Center (LExC) at LHO, for which $7.7M has been approved by Washington State for design, with construction making steady progress during 2021.
3. We will continue to organize a yearly International Physics and Astronomy Educator Program at LHO (online or in person, as appropriate).
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 and to adapt to post-pandemic constraints and opportunities.
6. We will assist Observatory staff with refreshing the range of LIGO and LVK merchandise available through cafepress.

### 2. Priorities in Formal and Higher Education

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 – online and face-to-face.

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.

6. We will organize, promote and deliver the LIGO (I)REU Programs that host undergraduate students undertaking research experiences with LSC scientists.

## 3. Priorities in Informal Education and Public Outreach

Priority areas for Informal Education and Public Outreach are as follows:

1. We will maintain, update and renovate the ligo.org website for informal learners and members of the public.

2. We will continue worldwide outreach and communication through social media (Twitter, Facebook, Instagram, Reddit) and other informal educational materials that showcase our community, 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. We will develop printable material and multi-lingual resources, including science summaries for all collaboration papers.

6. We will promote development of innovative approaches that communicate LVK 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 and promote Gravity Spy and other citizen science projects.

10. We will support LVK members communicating our science through public talks at local or national community events, including science festivals, museums, science centers, astronomy societies etc.

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

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

## 4. Priorities for Professional Outreach

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.
3. We will promote outreach to scientists / 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 informal educational activities and other outreach events, including e.g. engagement with politicians and funders.
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.

## 5. Priorities for Public Relations and Communications

Priority areas for Public Relations and Communications are as follows:

1. We will continue to support communication with media contacts and liaisons, and we will provide media guidance and training for collaboration members.
2. We will support and coordinate preparations for LVK public announcements of scientific results, particularly (but not only) O4 exceptional event papers and webinars.
3. We will help to develop a framework, appropriate for O4, for deciding when LVK papers are worthy of announcement as exceptional event papers and/or webinars, and for effective and efficient and effective management of these announcements.
4. We will maintain and produce public materials such as the LIGO Magazine.

## LSC EPO Committee: Present and Future

The LSC 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 2021, the LSC 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, before the end of 2021 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

# Contents

# 1 Introduction and overview

## 1.1 Our EPO Philosophy

This White Paper outlines the 2021-22 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 across the wider LVK – i.e. the LSC, Virgo Collaboration and KAGRA Scientific Collaboration – 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 LVK 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 and the LVK 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.

LVK outreach initiatives seek to inform the public not only about the exciting new science of gravitational waves and the activities of LIGO, Virgo and KAGRA, but also about science in general. LVK 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 LVK 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

[1] In 2020, following a comprehensive review of LSC structures and organisation, the LSC EPO working group was re-designated and re-organised as the Communications and Education (C&E) Division.

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

## 1.2 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 LVK 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 LVK EPO network is able to create outreach programs which are far more effective than they would be if LVK member institutions worked independently.

### 1.2.1 EPO Aims

The broad outreach aims of the LVK 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.

### 1.2.2 LSC EPO Objectives

The LSC's 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 KAGRA 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.).

### 1.3 Scope of our EPO Activities and Programs

LVK 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.

# 2 Our Global Approach to Communicating LVK Discoveries

This chapter provides a brief overview of our LVK approaches to communicating information about candidate events and confirmed detections to media professionals, other scientists, informal learners and the general public.

In the five years since the first gravitational wave detection was announced, the field has progressed from an epoch-making scientific breakthrough to an almost routine occurrence – but one for which the public appetite remains undiminished. As of July 2021, the number of confirmed compact binary merger detections that have been announced to the public has risen to more than 50 – with a population that now comprises examples of binary black-hole, binary neutron-star and neutron-star black-hole mergers. One of our flagship EPO materials that highlights this growing population is the "Stellar Graveyard" plot produced by Aaron Geller and Frank Elavsky on behalf of the Northwestern University LSC Group. The latest version of this plot, following the neutron star-black hole discovery announcement made in June 2021, can be found here. The evolution of this graphic since 2016 (compare it with e.g. this version, from the December 2018 publication of GWTC-1, or this version, from June 2017 following the detection announcement for GW170104) is one of the most striking and direct indications of the remarkable progress there has been in ground-based gravitational-wave astronomy.

## 2.1 Candidate Event Alerts

Since the beginning of our third Observing Run, on April 1st 2019, our global detector network began adopting a new approach to sharing information with the wider astronomical community and the general public. The bespoke Memoranda of Understanding that had operated during O1 and O2 with specific astronomical facilities and collaborations – spanning the EM spectrum and also involving the neutrino and cosmic ray astronomy communities – have now given way to open, low-latency public alerts that are communicated rapidly via GCN circulars[1] and collated/updated via the Gravitational-Wave Candidate Event Database (GraceDB)[2]. Further details about these rapid alerts and how to access them can be found in the LVK Public Alerts User Guide, available here.

Throughout O3, there was also a significant EPO dimension to communicating these candidate event alerts, with the Collaborations' social media platforms (particularly @ligo on Twitter) used to rapidly share information with the public. Our approach first made use of automated tweets, sent out very

[1] https://gcn.gsfc.nasa.gov/
[2] https://gracedb.ligo.org/

quickly after the GraceDB alert, then followed (usually within one or two hours) by human-generated tweets and posts aimed at providing broader context for the alert and employing analogies and everyday comparisons to explain the alert data in a more accessible manner.

Our O3 candidate alert social media strategy can be summarized by the following goals and approaches:

- Present **only** public information (i.e. information consistent with that available via GraceDB), avoiding any speculation or editorialising.
- Try to explain and demystify the scientific process involved in going from a low-latency alert to (much later) a confirmed detection.
- Specifically, emphasize both the excitement of discovery and the need for caution and meticulous and rigorous analysis of our data.
- Unpack and discuss the information contained in the alerts, particularly the initial source classification – e.g. what do we mean by the calculated "Mass Gap" or "HasRemnant" probabilities?
- Use lots of analogies and pop culture references to contextualize the alert information, particularly the distance and sky localization area.
- Emphasize the global nature of our efforts, always referring to LIGO and Virgo (and now KAGRA) in all posts and highlighting the large number of countries involved.
- Combine discussion of the source astrophysics, and its relation to EM and multi-messenger astronomy, with a focus on the remarkable instrumentation technology that underpins the ground-based detectors, and the diverse, multi-disciplinary, global research community that has enabled it.

A significant challenge for O4 will be how best to scale up this effort, with the improved sensitivity of the global network (augmented by KAGRA) yielding candidates on a daily basis. We anticipate continuing to combine the use of automated software to convey basic information with human-generated posts and tweets, We will also seek to ensure that we can respond quickly and efficiently to questions that our O4 candidate events generate. (See also Chapter 8 for further discussion of our social media strategy and O4 plans).

## 2.2 Exceptional Events and Other Announcements

O3 ended in March 2020, with the second part of O3 (denoted O3b, which ran for about 5 months from November 2019, following a one-month commissioning break in October 2019) coming after KAGRA officially joined the global LVK collaboration. Throughout 2020 and 2021 to date, a series of collaboration papers have been published presenting O3 results – with, generally, those featuring analysis of O3a data (April 2019 – September 2019) being authored by LIGO and Virgo collaboration authors, and those papers analyzing data from O3b or the entire O3 dataset being authored by LIGO, Virgo and KAGRA authors.

Some O3 papers have been featured as news items on our collaboration websites, and all have been highlighted on our social media platforms. A subset of papers and results have been featured more prominently, with coordinated LIGO and Virgo press releases and extensive media coverage. To date, these higher-profile O3 announcements have comprised (with links to detection pages on www.ligo.org):

- **January 2020:** GW190425. Second binary neutron star coalescence ever detected.
- **April 2020:** GW190412. Binary black hole coalescence with most asymmetric mass ratio detected to date.
- **June 2020:** GW190814. Detection of an even more asymmetric compact binary coalescence, consisting of a 23.2 solar mass black hole and a 2.6 solar mass 'mystery' companion that is either the heaviest neutron star or (more probably) the lightest black hole detected to date.
- **September 2020:** GW190521. Most massive binary black hole coalescence detected to date and the first ever observation of an intermediate mass black hole.
- **October 2020:** O3a Catalog. Publication of GWTC-2 catalog – consisting of 50 confident detections of compact binary coalescence events from O1, O2 and O3a – and companion papers.
- **June 2021:** GW200105 & GW200115. First ever confirmed detections of neutron star black hole binary coalescence events.

The levels of global media attention for these announcements have been very high – albeit not quite at the spectacular level of the GW150914 and GW170817 detection announcements in 2016 and 2017 respectively. The LVK EPO groups have coordinated production of a wide range of multimedia resources to support the announcements – including science summaries, infographics, fact sheets, simulations and artistic renderings. While some of these resources have been produced by professional graphic artists, many have been directly created by collaboration scientists themselves, and have been widely featured on newspapers and websites. This team effort has been a vital part of how we have informed the world about our new field. (The resources can be freely downloaded from the detection pages highlighted above).

The integrated LVK approach to our 'Exceptional Event' and other announcements has worked well, notwithstanding the challenges of coordinating and synchronising publicity across multiple different timezones. For most of the 2020-21 announcements the LVK has operated a 48-hour embargo period prior to the publication of the corresponding paper(s). In this approach LVK press releases were submitted under embargo to EurekAlert and approved EPO resources were curated on a secure Google drive. During the embargo period LVK groups could then share the contents of this drive with trusted journalists and liaise with journalists on preparing embargoed stories. Feedback on this approach has generally been very positive, although we will continue to review it – as well as considering carefully the appropriate 'threshold' of importance for generating press releases (or indeed press conferences) – as preparations for O4 continue.

With the COVID pandemic severely limiting opportunities for LVK scientists to attend face-to-face scientific conferences and present results, in June 2020 the LVK collaboration initiated a series of scientific webinars to present O3 results.

As of July 2021, there have been 8 such webinars held to date. These have featured the exceptional event discoveries listed above, from GW190814 onwards, and presentation of the GWTC-2 and its companion papers. In addition there have been webinars presenting O3 stochastic searches for cosmic strings and O3 search results for gravitational lensing. The webinars have been live-streamed on both Zoom and the LIGO-Virgo YouTube channel. Typical audiences have been in the range 500 – 1000, and the webinars have been an excellent opportunity to showcase among the presenters a large number of LVK scientists from across the world. A playlist of the LVK webinars can be found here.

# 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, LIGO Exploration Center (LExC), soon to be completed, 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 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 (including remote activities, where appropriate / required).

- 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 and to adapt to post-pandemic constraints and opportunities.
- We will assist Observatory staff with refreshing the range of LIGO and LVK merchandise available through cafepress.

## 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 work to develop the LIGO Exploration Center (LExC) at LHO, for which $7.7M has been approved by Washington State for design, with construction making steady progress during 2021.
- We will continue to organize a yearly International Physics and Astronomy Educator Program at LHO (online or in person, as appropriate).
- We will continue to work with collaborators from across astronomy to produce a multi-messenger astronomy masterclass.

## 3.4 LIGO India Observatory

### 3.4.1 Past and Current Activities

The LIGO-India Observatory will be located in the Hingoli district of Maharashtra state. The requirements of the project puts it in a relatively isolated region in India that is in a nascent stage of economic and industrial development. The project set up an EPO team (LI-EPO) from its inception with the following objectives

- To attract science and engineering students as well as faculty towards the project and GW Science
- To maintain continued interest in the project and create awareness amongst the general public
- To create and sustain goodwill and support from the communities residing near the actual project site

To address these, during the pre-pandemic era, the LI-EPO team regularly organised GW Science talks by GW experts from the LIGO-India Scientific Collaboration (LISC) at various science and engineering institutes across the country to engage with students and faculty at a personal level and also to create awareness about the project. LI-EPO also actively participated in popular national and international level annual college/ institute technical festivals like IIT-Bombay Techfest which usually boasts of a total footfall of 175,000.

LI-EPO regularly represents the project at national level exhibitions, like the Indian Science Congress, which has more than 12000 participants (delegates, scientists and academicians) from all across the country. A major highlight for LI-EPO was its participation in the "Vigyan Samagam" Mega Science Exhibition along with 7 other mega science projects viz. CERN, INO, ITER, FAIR, SKA, TMT and MACE. This exhibition was held from May 2019 to March 2020 in major metro cities Mumbai, Bangalore, Kolkata and Delhi, attracting a footfall of half a million.

Throughout the pandemic, LI-EPO was able to engage a large audience on both national and international level through various online initiatives like the GW@Home live online GW lecture series, special outreach events like the National Science Day celebrations, an interview with Nobel Prize winner Prof. Rainer Weiss, live tour of LIGO in Minecraft (in collaboration with OzGrav colleagues) and other GW talks and workshops targeting university and school students as well as general public. On the 5th anniversary of GW150914, LIGO India launched the GW Science blog "Gravity Matters".

The blog, hosted on the LIGO India website and advertised via LI social media pages, regularly publishes content on GW related sciences, features women working in GW Science, podcast interviews of renowned GW scientists, virtual gallery of GW science inspired art etc. Despite the challenges posed by the pandemic since April 2020, LI-EPO still managed to reach at least 61,402 school and college students, educators and the general public. During the first two weeks of July 2021, LIGO India in collaboration with the Newton-Bhabha fund organised a "Build a Detector" workshop for Masters and PhD students. This was the first workshop teaching students about GW instrument science and the related skills to design and concept-build a GW detector along with the likely signals to be measured. LI-EPO also prepared and distributed press releases of major GW discoveries and exceptional announcements with Indian media. Most of these, in English as well as vernacular languages, highlighted their Indian contributions and were well covered by the press. LI-EPO has also translated major LVK science summaries in vernacular languages.

#### 3.4.2 Needs and Future Plans

In preparation for post-pandemic EPO work, LI-EPO plans to prioritise on accomplishing the following in the next half decade.

- We will develop portable outreach resources and material
- We will interface better with national and regional media for enhancing awareness of the latest achievements in GW science amongst the Indian population
- We will organise and participate in online mega-science exhibitions similar to "Vigyan Samagam" reaching out to other cities across India
- We will mobilise efforts to popularise GW Science and create awareness about LIGO-India in primary and secondary Indian schools
- We will continue planning for the on-site LIGO-India Science Centre

In association with Newton-Bhabha funds, LIGO-India is designing a portable booth for outreach in India. A modular approach is being sought for this to scale it as per the requirements at hand. There is also a need for designing and fabricating hands-on outreach demos such as gravity well to accompany the booth. We plan to make introductory LIGO-India print material for outreach in English and Hindi and subsequently in other major vernacular languages.

In addition to the efforts being planned to organize events across Indian schools to popularise GW Science, LI-EPO is in touch with the Einstein First team from the University of Western Australia and is exploring the possibility of collaborating with them to extend their innovative and proven teaching methods to introduce fundamental concepts in modern physics at school levels. In the process LI-EPO also plans to contribute in developing methods particularly catered to the Indian curriculum.

In order to connect better with mainstream media personnel, LI-EPO is planning to conduct an introductory workshop customised for journalists and media professionals for reporting about GW Science. In the longer run this will enable LI-EPO to leverage the reach offered by mainstream media to create awareness about the upcoming LIGO-India Observatory and GW Science across the nation.

# 4 Education and Public Outreach of EGO and the Virgo Collaboration

This chapter provides a brief overview of education and public outreach activities of the Virgo Collaboration and the European Gravitational Observatory.

EGO, the European Gravitational Observatory, located in the countryside near Pisa in the Commune of Cascina, was created on 11 December 2000 by the Centre National de la Recherche Scientifique (CNRS) – a French public, scientific and technological institution, and the Italian Istituto Nazionale di Fisica Nucleare (INFN). The NIKHEF Laboratory in the Netherlands joined in 2007 with an observer status and in early 2021 as a member.

The Consortium has as its purpose the promotion of research in the field of gravitation in Europe. In this context the Consortium pursues the following objectives:

- to ensure the functioning of the VIRGO antenna, its maintenance, its operation and the improvements to be made
- to ensure the maintenance of the related infrastructures, including a computer centre and to promote an open co-operation in R&D
- to ensure the maintenance of the site;
- to carry out any other research in the field of gravitation of common interest for the Members
- to promote co-operation in the field of experimental and theoretical gravitational-wave research in Europe;
- to promote contacts among scientists and engineers, the dissemination of information and the provision of advanced training for young researchers.

The scientific responsibility of the Virgo detector is assumed by the Virgo collaboration.

EGO supports an extended program of communication and outreach, training, citizens' science and support of Art and Science events. Flagship examples include: a program of visits by Universities, schools and the public (over 8000 visits per year); researchers night events – with emphasis on diversity, gender and disabled citizens' issues; an EU-funded program (Frontiers) on communicating science to school teachers and students; computing training weeks and leadership of an EU-funded program (REINFORCE) on Citizens' Science.

The EU-funded 'Frontiers' program of collaboration with high school teachers brings high school teachers in Tuscany and elsewhere into contact with the science of Gravitational waves, and supports the organisation of workshops at EGO with these teachers and the conception and development of digital demonstrators of GW science – as well as e.g. EGO Control room VIRGO Virtual Visits.

The REINFORCE program through its workpackage “Increasing the senses, increasing inclusion” aims to extend the reach of the project to citizens with sense-disabilities (especially those who are visually-impaired), interact with senior citizens and explore the potential and the barriers for their engagement in citizen science. In this context we are developing a program of sonification of astronomical and environmental data, permitting visually impaired citizens to participate in the adventure of science, but also in return augmenting the discovery potential of gravitational- wave research by the inclusion of new sensorial (acoustic) data.

Last but not least EGO has participated in high visibility Art and Science exhibitions:

- the exhibition “On Air” by Tomas Saraceno at the Palais de Tokyo in Paris (October-December 2018), the most visited exhibition ever at this location.
- the exhibition “The rhythm of space” at the Museo della Grafica in Pisa (October-December 2019), bringing scientists and artists together to an exhibition that was praised by regional and national press and key experts in science and art. This exhibition will tour many European capitals (including Paris, Rome, Athens) in the coming years.

# 5 Education and Public Outreach of the KAGRA Collaboration

KAGRA is the laser interferometer with 3 km arm-length in Kamioka, Gifu, Japan. KAGRA completed its construction in 2019, and joined the international GW network of LIGO and Virgo. The actual data-taking was started in the final stage of O3b, February 2020. KAGRA collaborators started participating LVK meetings and telecons, and joined co-analysis of the data. KAGRA's authorship started from the papers which use O3b data.

The KAGRA Scientific Congress (KSC) is composed of over 460 members from 115 institutes in 14 countries/regions. The list of researchers is available from here. More than half of these researchers belong to universities or research institutes in Japan, but the collaborators come from many other Asian countries/regions, especially from China, Korea, and Taiwan. KAGRA's general information can be found at the website https://gwcenter.icrr.u-tokyo.ac.jp/en/. Resources for researchers are accessible from http://gwwiki.icrr.u-tokyo.ac.jp/JGWwiki/KAGRA.

## 5.1 Past and Current Activities

### 5.1.1 Activities by ICRR, at the KAGRA site

The host institute of KAGRA is the Institute of Cosmic Ray Researches (ICRR), the University of Tokyo, and the project is co-hosted by the National Astronomical Observatory in Japan (NAOJ) and the High Energy Accelerator Research Organization (KEK).

ICRR has a section for public relations, but only a few people cover all of their projects, including neutrino research (Super-Kamiokande, T2K, XMASS), high-energy cosmic ray research (Telescope Array, Cherenkov Cosmic Gamma Ray, Tibet AS$\gamma$ Experiment, ALPACA Experiment). KAGRA is rather a new group in ICRR, and one person has been assigned to work for KAGRA since 2017.

ICRR organizes many public communication events like public lectures, science café, and public open-days. In 2020, due to the pandemic of COVID-19, people's movements in Japan were strictly not recommended from March to August, and again from late November to December. (The situation continues in 2021. People are suggested to refrain from moving/traveling from January to March, and from April to June.) Under this situation, KAGRA organized the following events or reacted to external requests:

- Online lectures and tour at the site for public (5 events in November 2020)
- Online lectures and tour at the site for college students (November 2020)

- Online lectures and tour at the site for high-school students (4 times in October/November 2020)
- Visiting lectures for college students (October 2020)
- Visiting lectures for high-school students (July, October 2020)
- Face-to-Face lectures at local museums (October 2020 in Gifu, November 2020 in Miyagi, February 2021 in Tokyo)

All the public open days of the underground facility received applicants more than double of the capacity. In 2020, the open day (November 23) was held online, attracting 1700+ live views and 8000+ archive views from across the world.

#### 5.1.2 Activities by the KSC

The KAGRA Scientific Congress (KSC) started an EPO group under the KSC in Spring 2020. Reacting to the announcement from the board chair of KSC, 10+ members had raised their hand and the group started. Prior to that, there were several spontaneous activities from collaborators but no organization existed for EPO activities.

In order to encourage KSC collaborators to carry out EPO activities, KAGRA EPO had to begin by reaching consensus on how each contribution will help the projects, how each activity will create new experiences, and also why such activities are necessary. There were long discussions in the internal meeting about how we should count EPO activities towards the authorship of our scientific papers. In December 2020, KSC reached agreement that official EPO-related activities can be included, for the purpose of determining authorship, up to the level of one third of our research activities. Now KAGRA EPO is asked to define what are counted as official EPO activities; this task will be completed during the next year.

In early 2018, several KAGRA SNS channels were started:

- facebook.com/kagra.pr
- twitter.com/kagra_pr
- instagram.com/kagra.observatory

Initially these were unofficial channels "by KAGRA fans", but now all are official under KAGRA EPO. Messages are continuously posted about our achievements, events information, beautiful scenes of Kamioka town and so on – all prepared in a hybrid style of Japanese and English. The facebook page has 526 followers and the twitter account has 1,795 (as of April 2021). Some posts on Facebook got more than 3k views. On the other hand, the Instagram page is still under development and has only three posts and 58 followers.

KAGRA EPO are now regularly participating in translating science summaries into Japanese, Korean, Traditional Chinese, Simplified Chinese, and Vietnamese. The KSC also started to issue a newsletter, known as the *KSC Newsletter*: its primary purpose is for exchanging information for researchers, but it is publicly available via the web.

### 5.1.3 Appearances in Media

KAGRA welcomes many science reporters, photographers and television crews from Japan and overseas. They seemed really impressed by our huge underground instruments and scientists 'domesticating' the delicate equipment. Consequently, large numbers of great articles and programs have been published and broadcast. Some examples of international coverage are:

- Nature News Jan. 2, 2019, "Japan's pioneering detector set to join hunt for gravitational wave" [link]
- UTokyo Focus Apr. 18, 2019, "Tunnel of wonders" [link]
- Scientific American Nov. 1, 2019, "Inside the World's First Underground Gravitational-Wave Detector" [link]
- Symmetry Oct. 29, 2020, "Japan's KAGRA searches the sky for gravitational waves" [link]
- Nature Video Feb. 14, 2020, "Inside Japan's big physics" [link]

### 5.1.4 Resources of KAGRA

ICRR has already created some PR materials. Collaborating with Iwanami Audio-Visual Media, KAGRA's promotion video was released on YouTube (English version, Japanese version).

ICRR has also produced stunning graphics images in collaboration with CG designer Rey Hori. Photographer Enrico Sacchetti has taken ultra high-resolution photographs and provided them for various usage. These are available from KAGRA's gallery page.

## 5.2 Needs and Future Plans

The current main obstacle for KAGRA EPO is the lack of main contact person(s). ICRR, the main host institute of KAGRA, is looking for a person who will mainly work for the PR section especially in support of the Kamioka area research groups, but (as of July 2021) this is still an open position. Until this position is filled, all the EPO activities are side works of researchers, and will be difficult to advance quickly. In Japan, most such PR positions are appointments of few years. We think that the need and importance of making this appointment should be understood generally in the academic communities in Japan.

### 5.2.1 Plans in the coming year

- Among the Taiwanese groups, National Tsing Hua University and National Cheng Kung University are going to integrate art and technology to introduce gravitational wave science. The ultimate objective is to create some artworks inspired by gravitational wave science so that the general public can appreciate the beauty of science. The artworks will be using technology with interactive experience and will involve both KAGRA scientists and art students.
- For the educational purpose of getting an idea how we observe and extract gravitaional wave signals, a Japanese group is developing an application, "Joya-no-kane identifier". "Joya-no-kane" means temple bell rung 108 times on New Year's Eve, which can be heard from many places

if you live in Kyoto City. Each bell has its own frequency, and people can identify it from the sound. With a textbook explaining this procedure at high-school level, we will release a toolkit on how we extract gravitational wave signals.

# 6 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.

## 6.1 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.

## 6.2 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

### 6.2.1 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

## 6.3 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

## 6.4 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 took 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. Another virtual meeting is planned for September 2021). IGrav is in the process of establishing formal relationships with the Gravitational Wave International Committee (GWIC) and the International Society for General Relativity and Gravitation (ISGRG). In June 2021 Isa Cordero was elected as the IGrav representative on GWIC. EPO Colleagues are strongly encouraged to get involved with the IGrav initiative. More information can be found on https://www.igrav.org/.

## 6.5 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.

## 6.6 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.

## 6.7 Formal and Higher Education Priorities

Below is the list of 2021-22 Formal and Higher Education priorities for the EPO group (further context for our Higher Education priorities are given in Chapter 7):

- 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 – online and face-to-face.

- 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.
- We will organize, promote and deliver the LIGO (I)REU Programs that host undergraduate students undertaking research experiences with LSC scientists.

# 7 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 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 LVK 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 LVK-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") are 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 LVK-related science and technology into these courses is another natural avenue to widen our reach.

## 7.1 Faculty Professional Development Related to LIGO

Professional societies such as the AAS offer 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.

Best practices for developing on-line or face-to-face 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

## 7.2 Resources for College Faculty

Creating and maintaining a comprehensive list of resources about LIGO, Virgo and KAGRA 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 entirely online workshops in spring 2020 and spring 2021). 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 LVK-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 LVK science and/or technology. Examples from physics and astronomy (including some specifically in the gravitational-wave field) are:

- 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 LVK activities and resources should be submitted for inclusion in sites such as:

- ComPADRE Digital Library
- MERLOT
- National Science Digital Library

## 7.3 Resources for College Students

Although it would require considerable resources for LIGO, Virgo and KAGRA to create an entire one-semester course specifically about ground-based gravitational-wave science, 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.

## 7.4 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 LVK 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 colleagues with an interest in the more astronomically-related aspects of LVK research should consider applying for this program.

## 7.5 Summer Research Programs

Authentic research experiences in LVK-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 LVK groups to include student internship activities, especially for students that are under-represented in STEM.

## 7.6 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 6):

- 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 – online and face-to-face.
- 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.
- We will organize, promote and deliver the LIGO (I)REU Programs that host undergraduate students undertaking research experiences with LSC scientists.

# 8 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 LVK, these informal education activities span a very broad range in scope – from local initiatives that engage LVK 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 across the world.

## 8.1 Visual Media

As the Detection Era proceeds, it is vital that the LVK 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, i.e. setting context for the ongoing upgrades to the detectors.

Ideally these materials 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, where (for example) playlists of the LVK Webinar series initiated in June 2020 can be found, and other contributions to this channel are greatly encouraged. Assistance with curating this channel is also sought.

## 8.2 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 talks 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 LVK scientists. YouTube has also been successful at disseminating discovery announcements as evidenced by the live streaming of e.g. the GW170817 press conference and (more recently) the LVK Webinar series. As of July 2021, 8 webinars have been delivered on O3 results, with more planned for the coming months.

More generally, the web traffic generated to our sites has shown a significant and sustained increase 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.

### 8.2.1 Website re-design

We plan to undertake a major re-design and re-vamp of the ligo.org webpage over the next 12-18 months. The goals of this major project are as follows:

- To give the website a more visually appealing and flexible design, allowing easier embedding of social media and easier integration/placement of video and graphical elements.
- To create a better, more efficient and robust process for pushing updates.
- To better integrate all the various tools/resources that have been developed for the public. This integration could also include resources that have been developed for scientists within and external to the collaboration.

We welcome dedicated effort from across the LSC to help with this, via liaison with the Web Committee Chair.

One of the largest sets of curated content on ligo.org are the science summaries published there to explain the contents of each collaboration paper to the general public. These documents are developed in parallel for web publishing and as print handouts, and more details are given in Sec. 8.9.

## 8.3 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).

## 8.4 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.

## 8.5 Social Media

Social Media accounts and platforms maintained by the LVK include (all figures as of May 2021):

- **Facebook**:
  1. @LIGOScientificCollaboration: 31.8K followers
  2. @EGOVirgoCollaboration: 5.5K followers
  3. @kagra.pr: 550 followers
  4. *See also* @LIGOIndia: 8.5K followers
- **Twitter**:
  1. @ligo: 108.4K followers
  2. @ego-virgo: 11.3K followers
  3. @KAGRA_PR: 1.8K followers
  4. *See also* @LIGOIndia: 3.7K followers
- **Instagram**:
  1. @ligo_virgo: 10.5K followers
  2. *See also* @LIGOIndia: 3.5K followers
- **YouTube**:
  1. youtube/ligovirgo: 3.2K subscribers
  2. youtube/EGOtheVirgoCollaboration: 397 subscribers
  3. *See also* youtube.com/c/LIGOIndia: 6.1K subscribers

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.

LVK EPO members are strongly encouraged to contribute to the teams 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.

Despite their enormous and sustained growth since early 2016 (for reference, 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 has been very effectively utilized by the LVK. The Reddit AMA (Ask Me Anything) forums organized in February 2016, June 2016, and October 2017 were an enormous success. Involvement by LVK EPO members in future AMA and related activities (e.g. Google hangouts) is strongly encouraged.

For several years the most widely read LSC scientist blog has been 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, and recently the LIGO India EPO team has introduced an excellent student-led blog called Gravity Matters. All are excellent examples of individual or team efforts that have an impact that greatly exceeds its cost, and similar efforts by a diverse set of LVK scientists are greatly encouraged.

The "Humans of LIGO" blog (https://humansofligo.blogspot.com/) is a recent endeavor that profiles an LSC (or sometimes LVK) 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 LVK 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 LVK 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. In 2020 the system for managing incoming questions and curating their replies was re-vamped, and ongoing work will explore ways to do this even more efficiently – ideally combining with a re-launched FAQ page on the ligo.org website.

The EPO group welcomes the help of more LSC members to assist with these activities – particularly in boosting the pool of 'first responders' willing to reply promptly and constructively to question@ligo.org inquiries.

Finally, following the detection announcements there has been significantly increased activity on LVK-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 LVK members, there is no issue with LVK members monitoring - and where appropriate editing - Wikipedia pages. The EPO group would greatly welcome colleagues willing to assist with this task.

## 8.6 Apps and Software Tools, Computer and Board Games

The LVK 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 IPython notebooks.

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

Best practices 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 (see also next sub-section). 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.

## 8.7 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.

## 8.8 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, and the LSC has participated in several of these exhibitions – including some jointly with LISA and NANOGrav colleagues. 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 published on this project in American Journal of Physics (also on arXiv) and a website publishes design specifications and instructions for others to build their own versions.

## 8.9 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.

#### LIGO Magazine

The LIGO Magazine is a publication from the LSC available online at `www.ligo.org/magazine`. Issues have been published twice-yearly since 2012. It is a high visibility product with great accessibility by the general public and value within the LSC. The readership includes both the public and members of the gravitational-wave community.

The LIGO Magazine features news from around the gravitational-wave community, captures the personal stories behind the science, and shines a spotlight on the many outreach and engagement activities talking place around the community. It provides an opportunity for early career researchers to write their take on the big discoveries and the day-to-day activities of the collaboration. Recent highlights include 'LIGO in Lockdown' (issue 17) which collated experiences of working from home during the COVID-19 pandemic and a cross-disciplinary article showcasing works of art and music inspired by gravitational-waves (issue 18). Regular features include an advice column written by and for early career researchers in collaboration with the LAAC ('LAAC Corner'), updates from past collaboration members on their new work and positions ('Work After LIGO'), quick-read explainers of gravitational-wave science topics ('How it works'), and updates from the LISA community ('Meanwhile in Space').

The LIGO Magazine Editorial Team are volunteers from the collaboration. They represent an outstanding effort in deciding the themes and topics of each issue, working with authors to ensure material is pitched at the right level, and getting each issue ready on time for release to coincide with the LVK collaboration meetings. LVK EPO members and the broader LVK community are strongly encouraged to contribute to future issues.

#### Science Summaries

A significant EPO activity has been the creation of an online 'Science Summary' website with summaries to accompany new LSC/LVC/LVK publications. These are aimed at the general public, but especially at the level of a scientifically literate non-specialist, also including students in higher education and, for inquisitive ones, already towards the end of secondary education. Dozens of LSC, Virgo and KAGRA members have written and contributed to reviewing science summaries that are now posted on ligo.org. Stand-alone and attractively formatted pdf versions of these science summaries are also being produced and available for download from the same website as well as from DCC. These are aimed in particular for distribution as paper hardcopies at e.g. science fairs and other outreach events.

Science summaries for each collaboration paper are now a collaboration deliverable and a dedicated task in the paper management and editorial team responsibilities. They are usually checked and improved by 2 assigned reviewers and at least one of the lead editors of the summaries project. In addition, translations into languages other than English have become a major part of this activity over recent years, with 22 different languages having received a translation of at least one summary so far, and the GW190521 discovery summary holding a record of 16 translations of a single summary. We aim to further increase the coverage of translations both in raw numbers as well as in increasing diversity of global distribution and topics covered.

On the technical side, besides an overhaul of the ligo.org website infrastructure, the procedures for drafting, reviewing and publishing science summaries and their translations would hugely benefit from efforts towards gitlab integration, automated pipelines and format conversions, as well as an effort (ongoing but requiring more personpower) to produce a centralized glossary resource that can be reused by new summary authors.

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.

**Poster**

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".

## 8.10 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. As time and talent permits LSC EPO members are encouraged to develop similarly creative endeavors. Some excellent recent examples of art-science collaborations inspired by gravitational waves are showcased in Issue 18 of the LIGO Magazine.

## 8.11 Multilingual Outreach

International members of the LVK are active in translating EPO materials 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.

## 8.12 Outreach to Children

Additional resources are needed to do effective outreach to children who may be 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. A related 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. A LIGO coloring book is also currently under development, aimed at highlighting the global, diverse and inclusive nature of the collaborations.

## 8.13 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.

## 8.14 Priorities for Informal Education and Public Outreach

Priority areas for Informal Education and Public Outreach are as follows:

- We will maintain, update and renovate the ligo.org website for informal learners and members of the public.
- We will continue worldwide outreach and communication through social media (Twitter, Facebook, Instagram, Reddit) and other informal educational materials that showcase our community, 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.
- We will develop printable material and multi-lingual resources, including science summaries for all collaboration papers.
- We will promote development of innovative approaches that communicate LVK 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 and promote Gravity Spy and other citizen science projects.
- We will support LVK members communicating our science through public talks at local or national community events, including science festivals, museums, science centers, astronomy societies etc.
- We will support LVK 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 9, 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.

# 9 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:

1. other scientists, particularly colleagues in the home departments of LVK groups, as well as scientists in fields that have the potential to overlap with gravitational wave physics (astronomy, optics, computational physics, etc.)
2. the broader academic community, including university administration, as well as program officers at funding agencies and/or foundations
3. 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:

1. organizing and participating in national and international conferences, and in online webinars, to disseminate the collaborations' scientific results;
2. 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;
3. organizing workshops, parallel sessions and other special events (e.g. exhibitions) and sessions at national and international meetings;
4. developing and promoting collaborative meetings and workshops between other scientists and gravitational-wave communities;
5. encouraging broad-based professional engagement through giving colloquia and other presentations at universities and laboratories.

## 9.1 Priorities for Professional Outreach

Priority areas for Professional Outreach are as follows:

- 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.
- We will promote outreach to scientists / 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 informal educational activities and other outreach events, including e.g. engagement with politicians and funders.
- 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.

## 9.2 Priorities for Public Relations and Communications

Priority areas for Public Relations and Communications are as follows:

- We will continue to support communication with media contacts and liaisons, and we will provide media guidance and training for collaboration members.
- We will support and coordinate preparations for LVK public announcements of scientific results, particularly (but not only) O4 exceptional event papers and webinars.
- We will help to develop a framework, appropriate for O4, for deciding when LVK papers are worthy of announcement as exceptional event papers and/or webinars, and for effective and efficient and effective management of these announcements.
- We will maintain and produce public materials such as the LIGO Magazine.