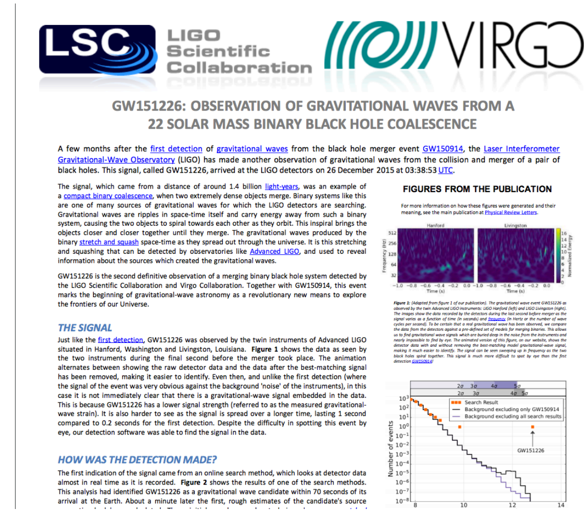
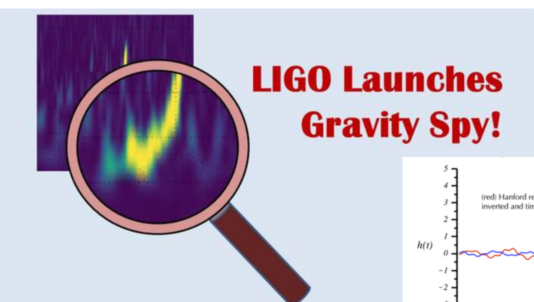
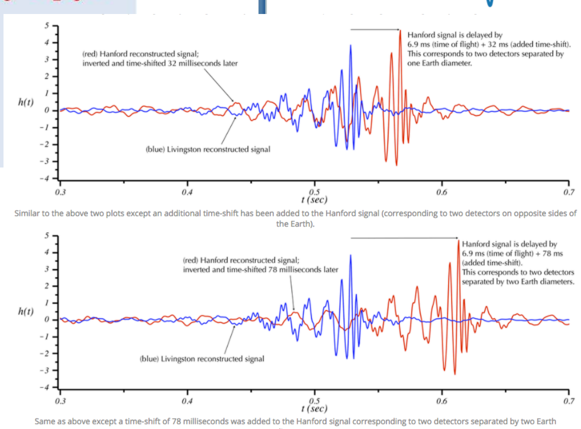
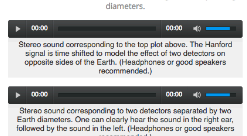
Overview of Education and Public Outreach (EPO) Activities of the LSC









Marc Favata (for the LSC)
Montclair State University

LIGO DCC: G1701204

This talk...

- Overview of work undertaken by the LSC EPO work.
- Summary of kinds of activities (not a complete list).
- Highlighting (i) things I like, (ii) resources useful for this audience.
- See public EPO whitepaper for more information: https://dcc.ligo.org/LIGO-T1600118/public
- Thanks to those who helped with this talk, esp: Joey Key, Martin Hendry, Jonah Kanner, Shane Larson, Ryan Lang, Veronica Kondrashov, ...

Brief history of the EPO group

LSC Charter: "...carry out an outreach program to communicate LIGO's activities and goals to the public, and to provide educational opportunities to young people." [https://dcc.ligo.org/M980279/public]

LIGO Labs started outreach programs following construction completion in 1998. EPO group started in 2008.

Past EPO group chairpersons:
Marco Cavaglia, Szabi Marka, Joey Key, Martin Hendry (current).

Individual LSC institutions/groups commit annually to perform certain EPO tasks (coordinated through the EPO group). >50% of LSC groups have an EPO contribution.

Goals:

communicate LIGO science; improve general scientific literacy; increase participation in science and recruitment to STEM careers (for *everyone*).

General EPO activities

- **lectures** on LIGO/GWs to school groups of all ages, the general public, specific groups; classroom visits.

- **outreach booths:** tables w/ brochures, flyers, stickers, and hands-on activities (small interferometer, videos, video games, "spacetime spandex", ...).
  World Science Festival, USA Science & Engineering Festival, NorthEast Astronomy Forum, Royal Soc. Summer Science, SACNAC, Exhibition, White House Frontiers Conference

- **booths at professional meetings:** APS, IAU, Royal Society Summer Exhibition.

- **government outreach:** brainstorming meeting after last APS meeting.

General EPO activities

- organizing press and media materials for LIGO discoveries.
- developing printed or online materials on GW science.
- teacher professional development: develop materials to integrate GW science into curricula at all levels; online courses for teachers.
- REU (research experiences for undergraduates) programs at LIGO member universities (e.g., large programs at Univ. of Florida, LSU, UT Rio Grande Valley, Caltech...).

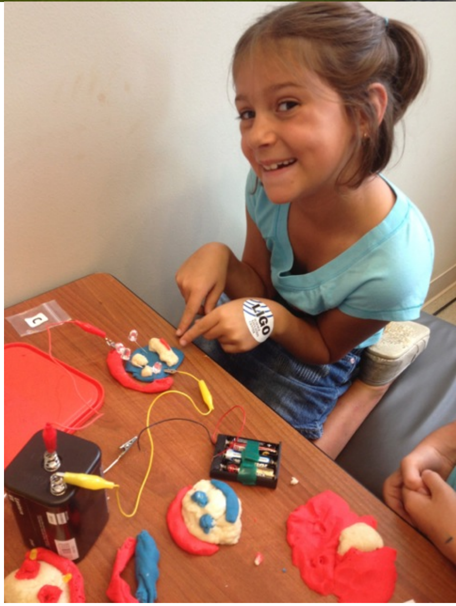
- musical or artistic works based on GWs.
- answering public questions: question@ligo.org .

LIGO Lab

- Science Education Center
  (Livingston site; a mini science museum)

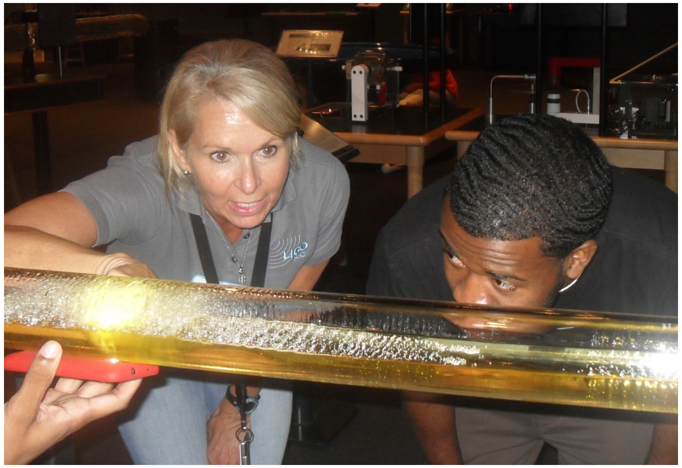
- smaller exhibit hall at Hanford.

- tours of LIGO
  ~8000(H) to 12000(L) yearly on-site contacts.



- school field trips.

- teacher workshops.

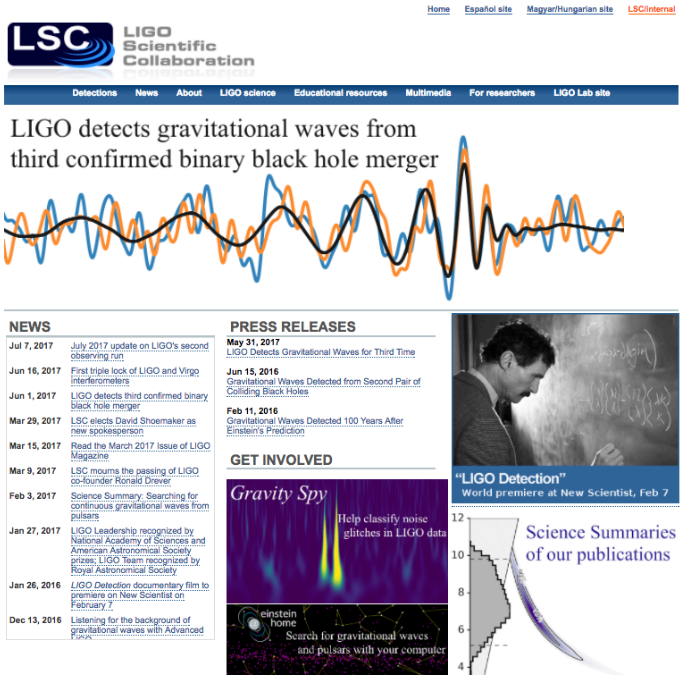


ligo.org

LSC's main global communication tool.

Key products:

- updates on LSC news/events.
- "detection" pages
  (links to publications, press releases, and
  related multimedia).
- science summaries.
- collecting/curating resources
  of the EPO group.
- general info about the LSC.

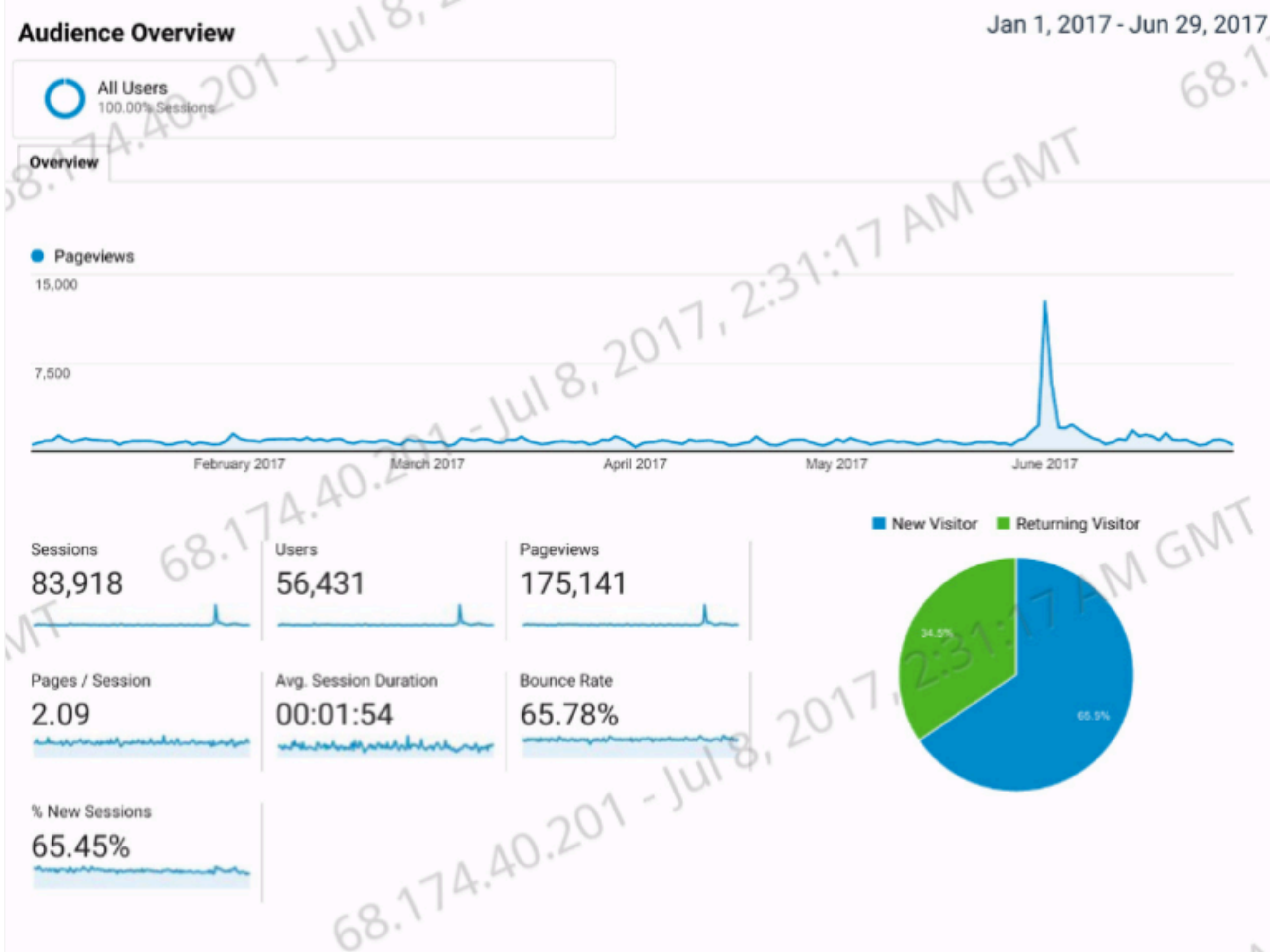


ligo.org

web stats:

first 6 months of 2017

~9400 users/month



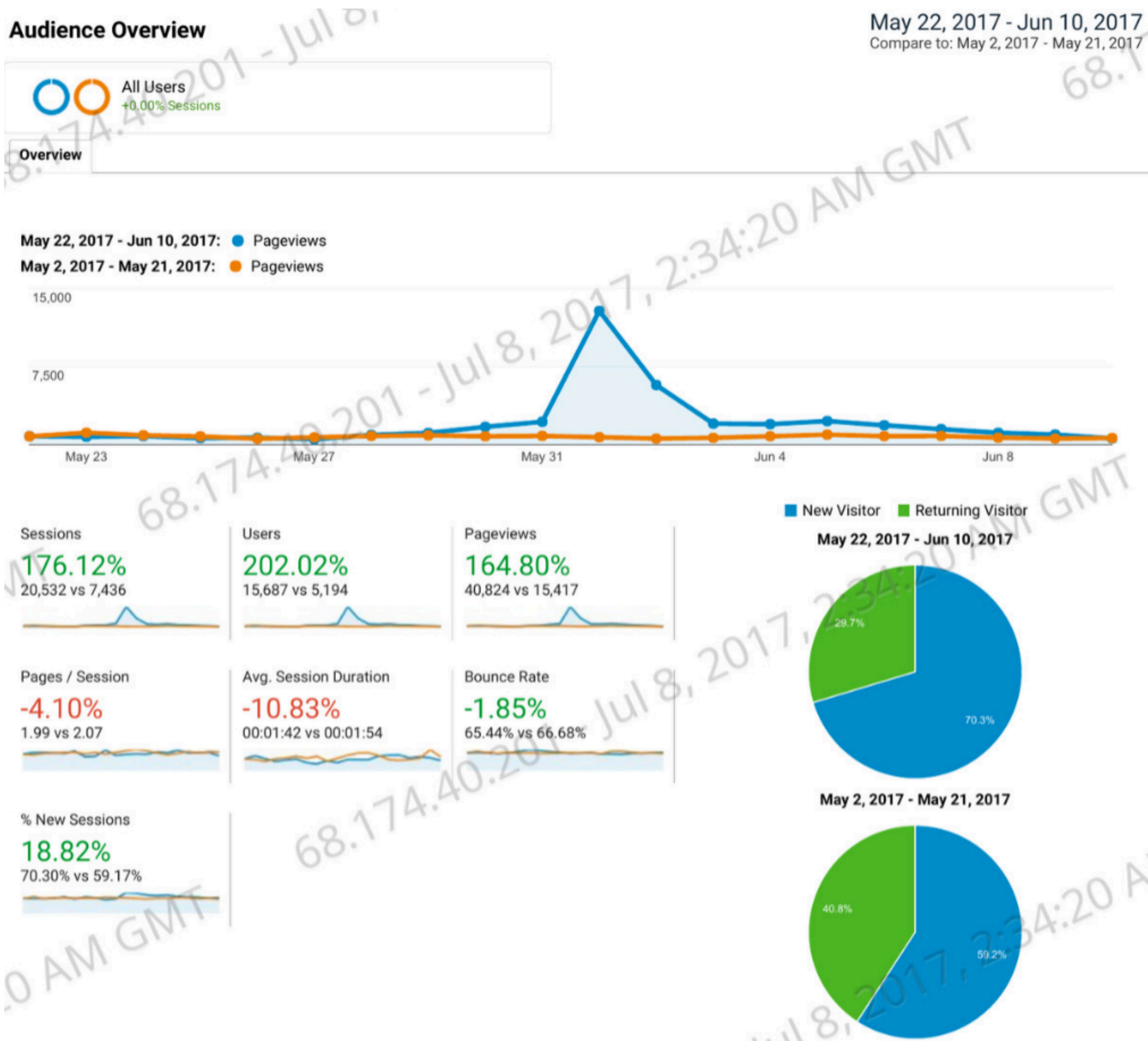
	Country	Sessions	% Sessions
1.	United States	26,838	31.98%
2.	United Kingdom	6,185	7.37%
3.	Germany	4,902	5.84%
4.	India	4,498	5.36%
5.	Spain	3,619	4.31%
6.	Italy	3,053	3.64%
7.	China	2,561	3.05%
8.	Australia	2,406	2.87%
9.	Canada	2,337	2.78%
10.	France	2,280	2.72%

ligo.org

web stats:

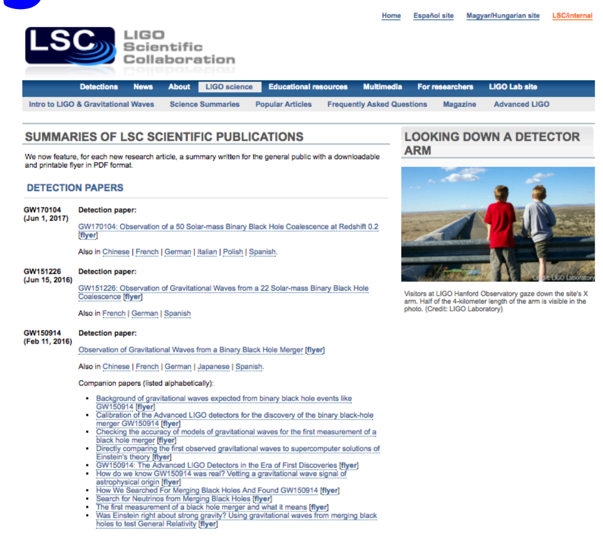
19 d period, typical vs. detection

~3x more users



ligo.org: science summaries

- *one of our key EPO products.*
- web page summaries of published papers; also pdf “flyer” versions for handouts at booths/ events.
- produced by members of paper writing teams and further edited by EPO.
- translations (~5 languages) for detection summaries.
- ~66 summaries since 2011.


Home Español site Magyar/Hungarian site LSC/Internal

LIGO Scientific Collaboration

Detections News About LIGO science Educational resources Multimedia For researchers LIGO Lab site

Intro to LIGO & Gravitational Waves Science Summaries Popular Articles Frequently Asked Questions Magazine Advanced LIGO

SUMMARIES OF LSC SCIENTIFIC PUBLICATIONS

We now feature, for each new research article, a summary written for the general public with a downloadable and printable flyer in PDF format.

DETECTION PAPERS

GW170104 (Jun 1, 2017) Detection paper:
GW170104: Observation of a 50 Solar-mass Binary Black Hole Coalescence at Redshift 0.2 [flyer]
Also in Chinese | French | German | Italian | Polish | Spanish.

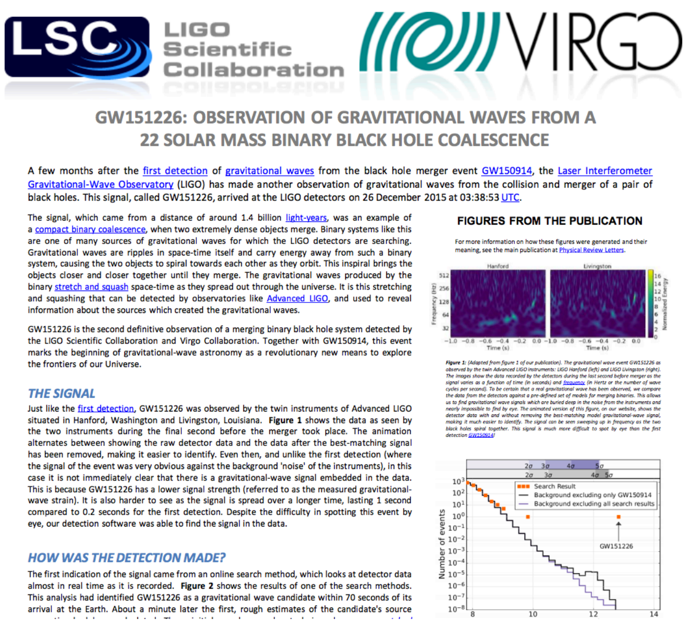
GW151226 (Jun 15, 2016) Detection paper:
GW151226: Observation of Gravitational Waves from a 22 Solar-mass Binary Black Hole Coalescence [flyer]
Also in French | German | Spanish

GW150914 (Feb 11, 2016) Detection paper:
Observation of Gravitational Waves from a Binary Black Hole Merger [flyer]
Also in Chinese | French | German | Japanese | Spanish.

Companion papers (listed alphabetically):
- Background of gravitational waves expected from binary black hole events like GW150914 [flyer]
- Calibration of the Advanced LIGO detectors for the discovery of the binary black-hole merger GW150914 [flyer]
- Checking the accuracy of models of gravitational waves for the first measurement of a black hole merger [flyer]
- Directly comparing the first observed gravitational waves to supercomputer solutions of Einstein's theory [flyer]
- GW150914: The Advanced LIGO Detectors in the Era of First Discoveries [flyer]
- How do we know GW150914 was real? Vetting a gravitational wave signal of astrophysical origin [flyer]
- How We Searched For Merging Black Holes And Found GW150914 [flyer]
- Search for Neutrinos from Merging Black Holes [flyer]
- The first measurement of a black hole merger and what it means [flyer]
- Was Einstein right about strong gravity? Using gravitational waves from merging black holes to test General Relativity [flyer]

LOOKING DOWN A DETECTOR ARM

Visitors at LIGO Hanford Observatory gaze down the site's X arm. Half of the 4-kilometer length of the arm is visible in the photo. (Credit: LIGO Laboratory)


LIGO Scientific Collaboration VIRGO

GW151226: OBSERVATION OF GRAVITATIONAL WAVES FROM A 22 SOLAR MASS BINARY BLACK HOLE COALESCENCE

A few months after the first detection of gravitational waves from the black hole merger event GW150914, the Laser Interferometer Gravitational-Wave Observatory (LIGO) has made another observation of gravitational waves from the collision and merger of a pair of black holes. This signal, called GW151226, arrived at the LIGO detectors on 26 December 2015 at 03:38:53 UTC.

The signal, which came from a distance of around 1.4 billion light-years, was an example of a compact binary coalescence, when two extremely dense objects merge. Binary systems like this are one of many sources of gravitational waves for which the LIGO detectors are searching. Gravitational waves are ripples in space-time itself and carry energy away from such a binary system, causing the two objects to spiral towards each other as they orbit. This inspiral brings the objects closer and closer together until they merge. The gravitational waves produced by the binary stretch and squash space-time as they spread out through the universe. It is this stretching and squashing that can be detected by observatories like Advanced LIGO, and used to reveal information about the sources which created the gravitational waves.

GW151226 is the second definitive observation of a merging binary black hole system detected by the LIGO Scientific Collaboration and Virgo Collaboration. Together with GW150914, this event marks the beginning of gravitational-wave astronomy as a revolutionary new means to explore the frontiers of our Universe.

THE SIGNAL

Just like the first detection, GW151226 was observed by the twin instruments of Advanced LIGO situated in Hanford, Washington and Livingston, Louisiana. Figure 1 shows the data as seen by the two instruments during the final second before the merger took place. The animation alternates between showing the raw detector data and the data after the best-matching signal has been removed, making it easier to identify. Even then, and unlike the first detection (where the signal of the event was very obvious against the background 'noise' of the instruments), in this case it is not immediately clear that there is a gravitational-wave signal embedded in the data. This is because GW151226 has a lower signal strength (referred to as the measured gravitational-wave strain). It is also harder to see as the signal is spread over a longer time, lasting 1 second compared to 0.2 seconds for the first detection. Despite the difficulty in spotting this event by eye, our detection software was able to find the signal in the data.

HOW WAS THE DETECTION MADE?

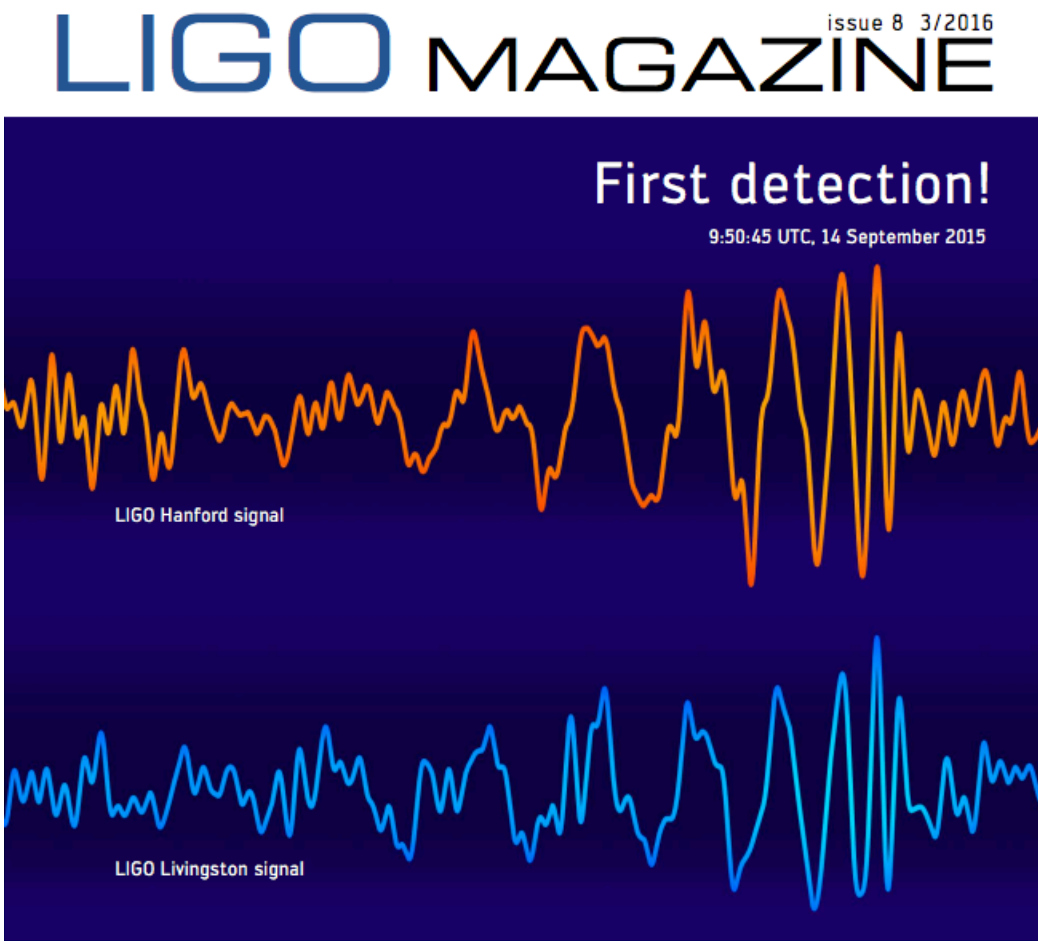
The first indication of the signal came from an online search method, which looks at detector data almost in real time as it is recorded. Figure 2 shows the results of one of the search methods. This analysis had identified GW151226 as a gravitational wave candidate within 70 seconds of its arrival at the Earth. About a minute later the first, rough estimates of the candidate's source

FIGURES FROM THE PUBLICATION

For more information on how these figures were generated and their meaning, see the main publication at Physical Review Letters.

ligo magazine

- highlights news, research, events, personal stories from within the LSC.
- published twice per year.
- focused on internal LSC audience, but useful to others in GW community.
- 10 issues so far.
- http://ligo.org/magazine/



social media

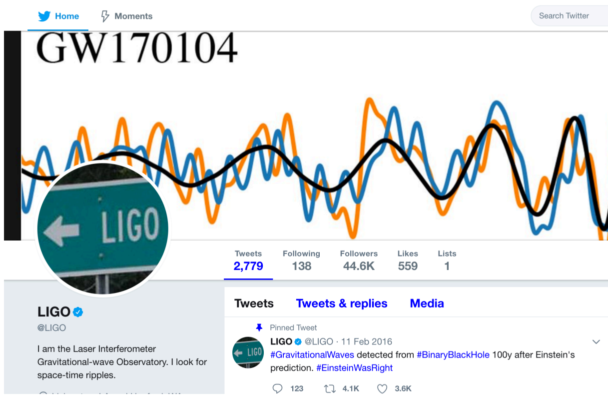
LSC promotes LIGO news and EPO activities via facebook and twitter.
(links at bottom of ligo.org)

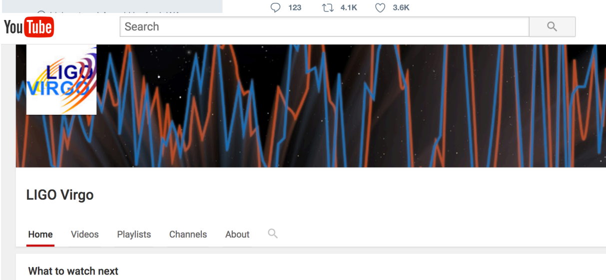
facebook stats: ~18,750 followers.
GW170104 post reached ~35,000 people.

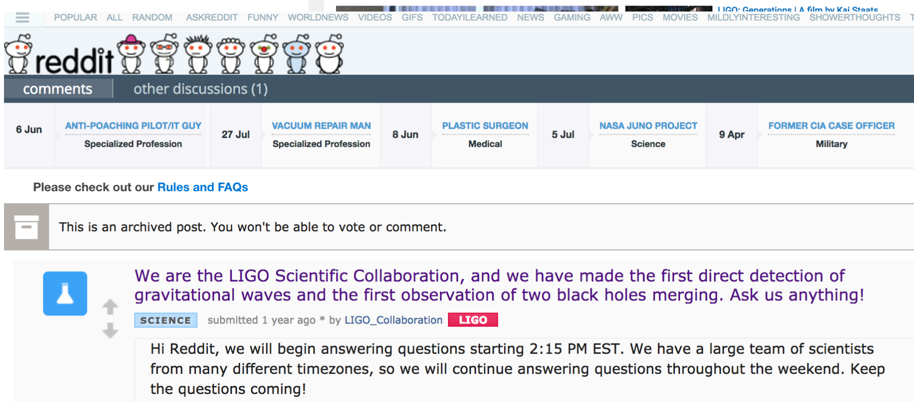
twitter stats: ~45,000 followers.
~1.8 million views in June 2017.
~70 million reached for GW150914.

youtube page: collection of LIGO-related videos.

reddit: AMA (“ask me anything”) events for 3 detections hosted by LSC members.

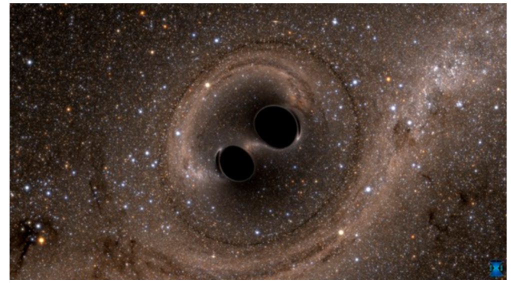


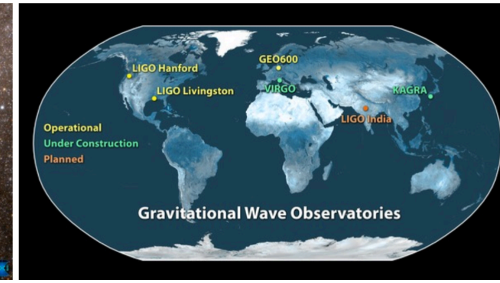


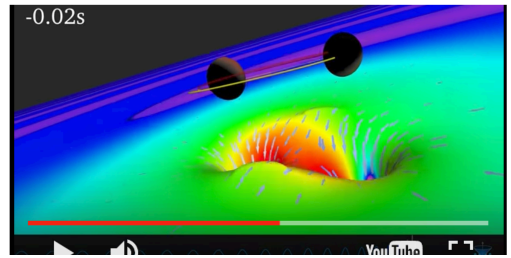


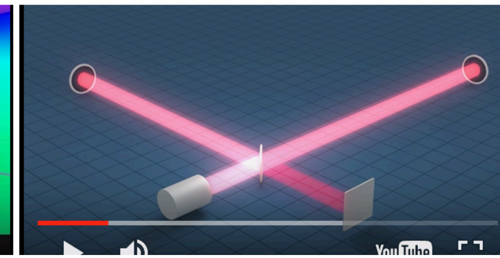
detection-related multimedia products

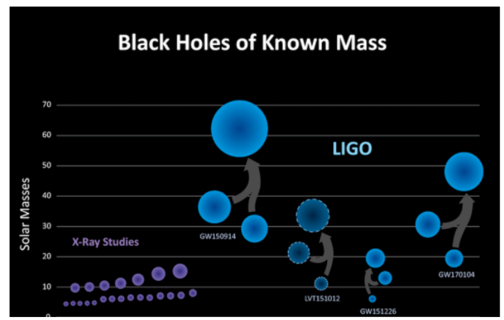
- videos, animations, NR simulations, interview clips.
- figures, images, and artists' illustrations for use by media.
- factsheets and infographics on detected events.
- available at ligo.org, ligo.caltech.edu

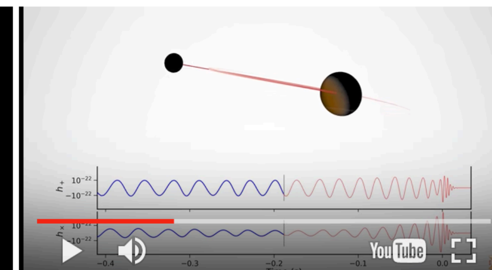




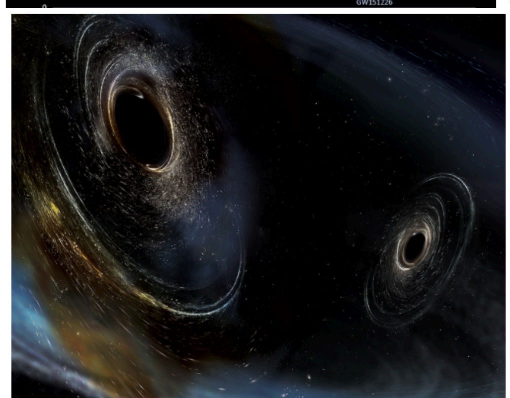


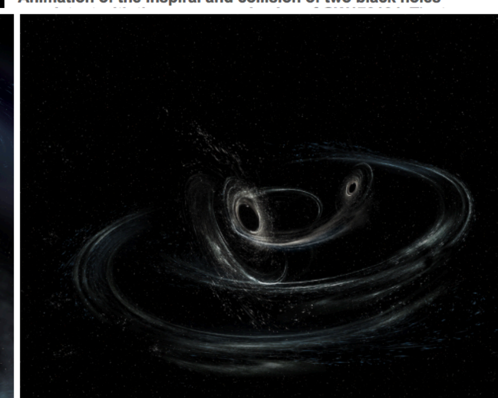






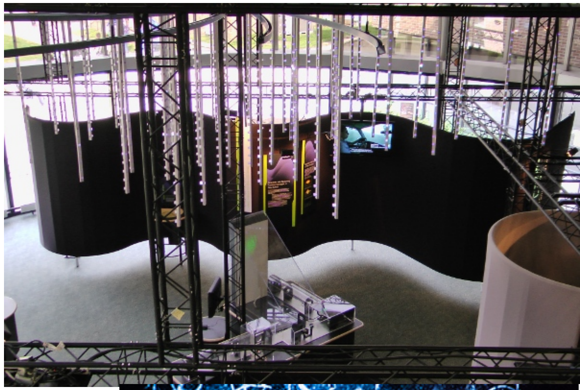
Animation of the inspiral and collision of two black holes





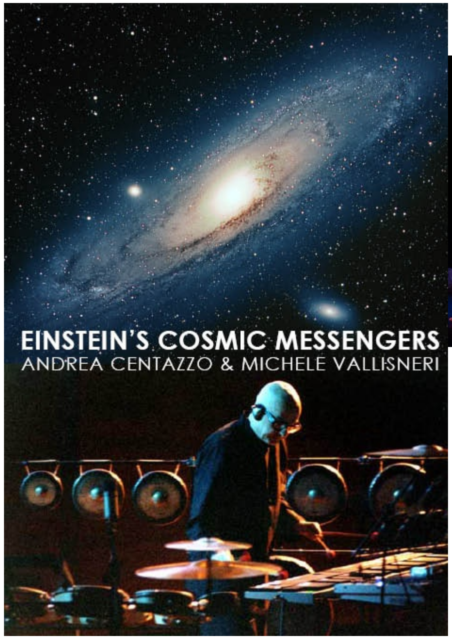
museum and artistic exhibits

- traveling exhibit: "Astronomy's New Messengers." http://ligo.phy.olemiss.edu/LIGOexhibit/



- http://celebratingeinstein.org/
series of events including "black (w)hole" audio/visual art installation, "a shout across time" dance-interpreted lecture + original film w/ live orchestra.

- Centazzo/Vallisneri's multimedia concert http://andreacentazzo.com/ecm/



- GWs & exoplanets music project (Arthur Jeffes) http://www.epcmusic.com/space

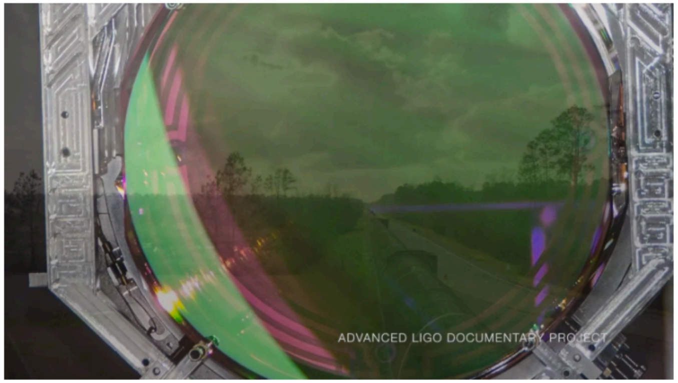
- "Chasing the waves" musical comedy (Glasgow).
http://www.gla.ac.uk/events/sciencefestival/eventsandprojects/projects/chasingthewaves/

films

- 3 LIGO films by Kai Staats (Over the Sun LLC) https://vimeo.com/album/3233854
- "Listening to the Universe" VR film https://with.in/watch/the-possible-listening-to-the-universe/
- advanced LIGO documentary project: https://vimeo.com/ligofilms
- short video interviews by GEO600 Team: http://scienceface.org/

LIGO Detection
6 months ago

LIGO Generations
2 years ago

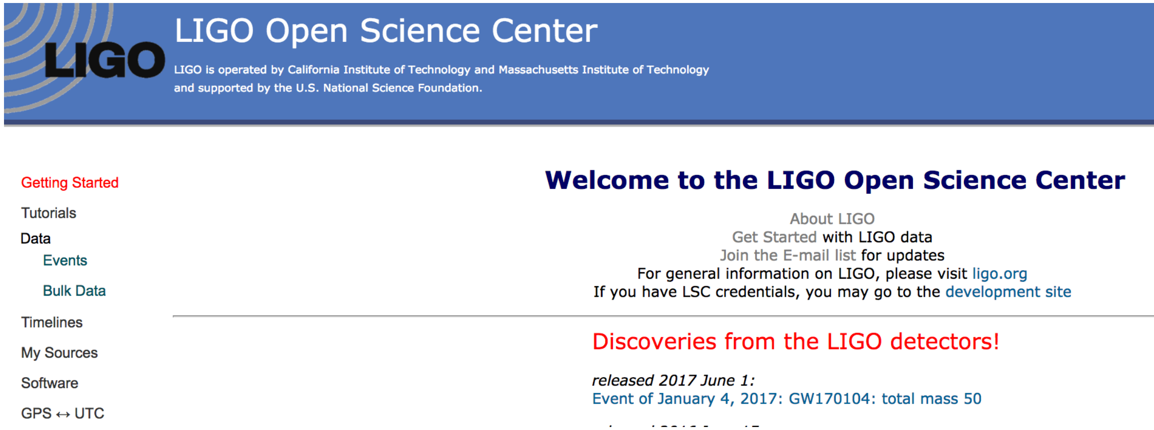


Mirrors That Hang On Glass Threads
aLIGO Documentary Project | 5344 plays

LIGO, A Passion for Understanding
2 years ago

LIGO Open Science Center (LOSC)

Main public portal
for LIGO data:
losc.ligo.org



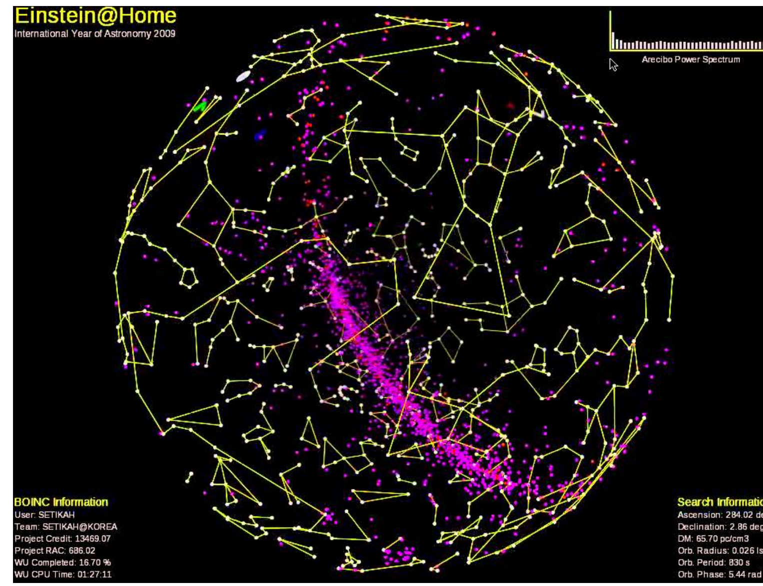
key products:

- h(t) data segments near detected events.
- past (S5, S6) and future data releases for science/observing runs.
- some data from publication figures.
- documentation and software tools for using data.
- python-based tutorials: play with data to extract detected signals.
- ~100 users/day

Citizen science: Einstein@home

- distributed computing project; analyzes data during computer's idle time.

- search for continuous GWs from spinning neutron stars. Also look for new pulsars in radio or gamma-ray data.

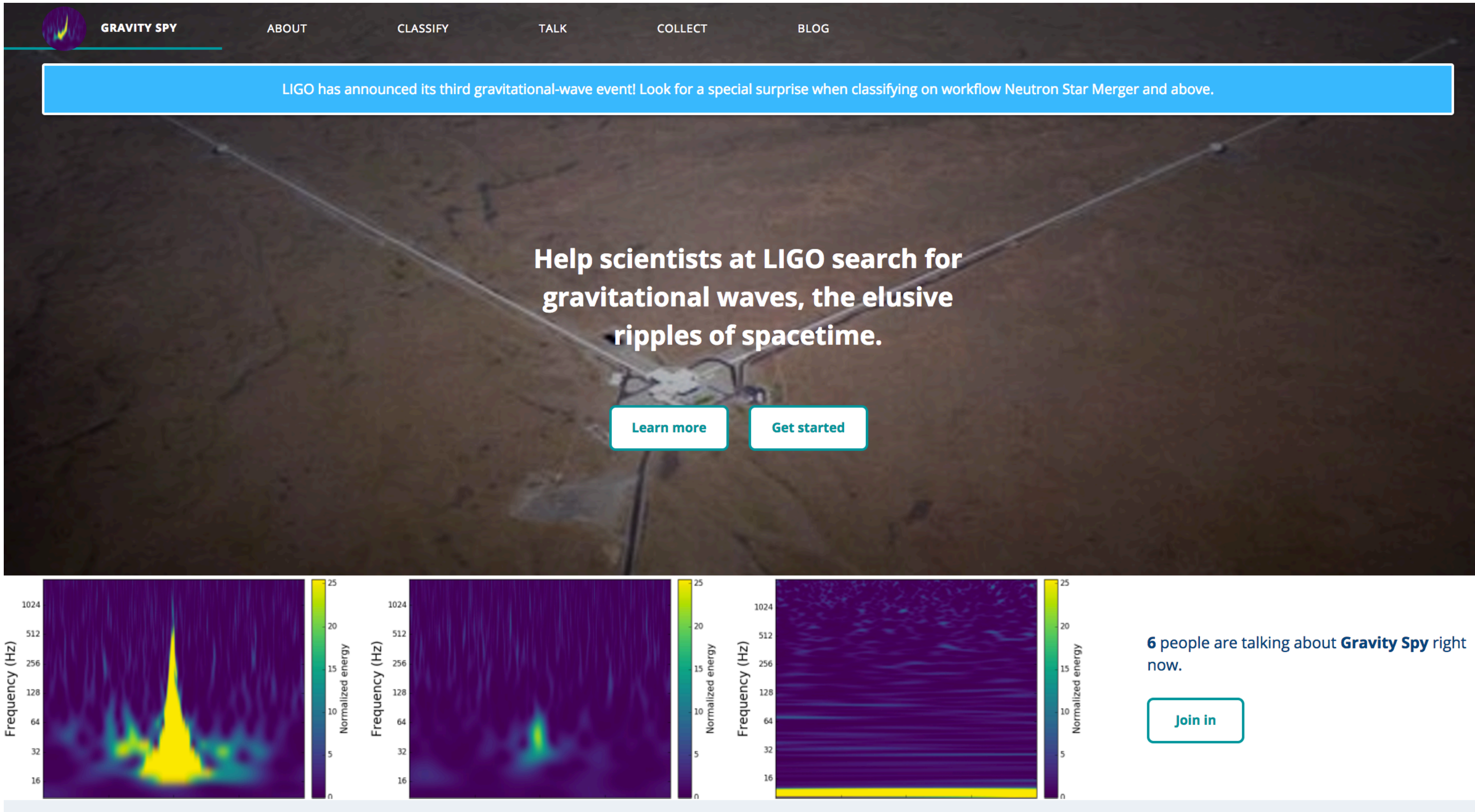


- Key recent results:
  - 13 new gamma-ray pulsars (Jan. 2017).
  - most massive double neutron star system (Nov. 2016).
  - measurement of braking index of new gamma-ray pulsar (Nov. 2016).
  - 13 new radio pulsars discovered (Aug. 2016).
  - limits on GW amplitude and ellipticity from spinning neutron stars (Sep. 2016).

(einsteinathome.org)

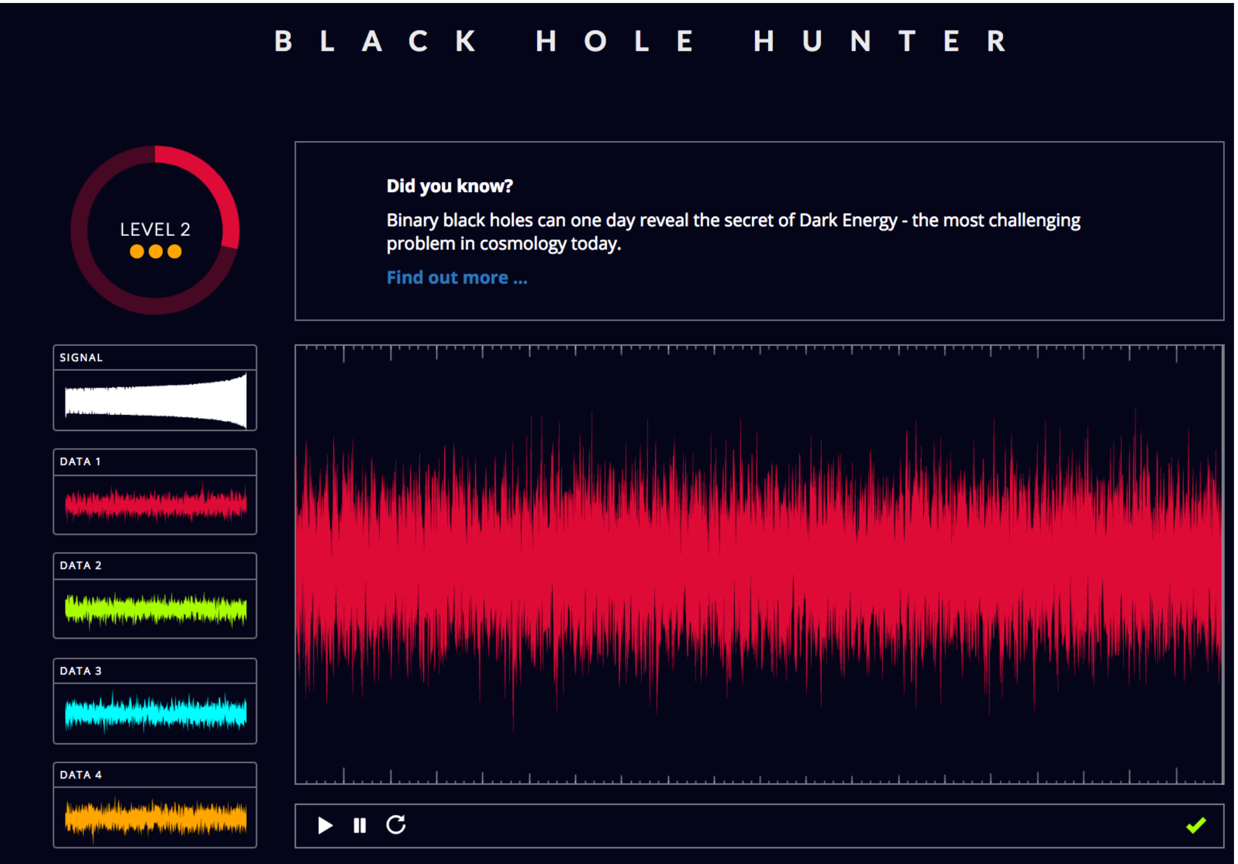
Citizen science: GravitySpy.org

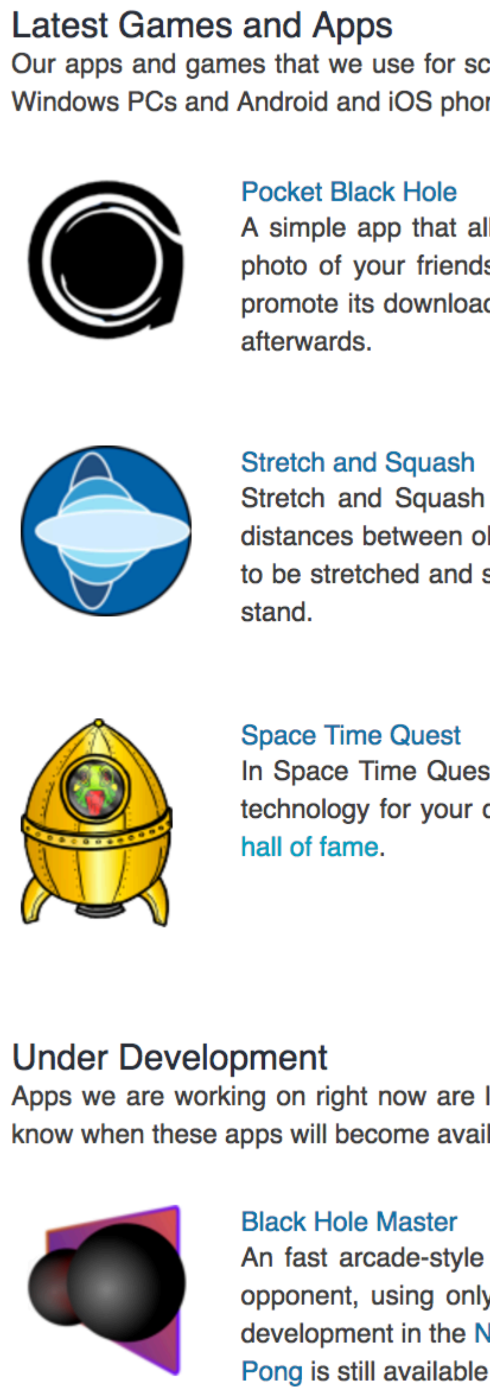
- volunteers help classify LIGO glitches; train machine learning algorithm and identify new glitch classes.
- ~9000 volunteers,   ~2.2 million glitches classified.
- currently using O2 data.



Games & apps

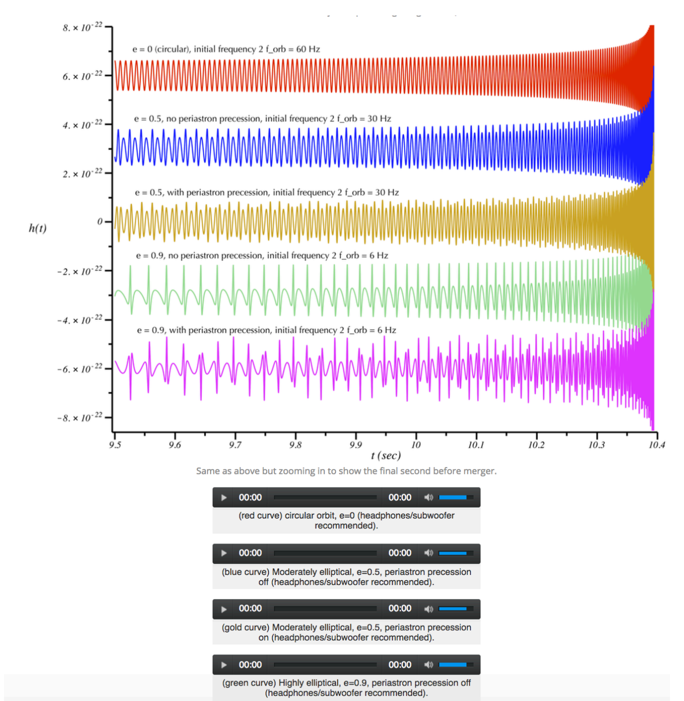
- 4 games/apps developed by laserlabs.org, gwoptics.org (U. of Birmingham)
- Black Hole Hunter (Cardiff. U.); http://blackholehunter.org/





soundsofspacetime.org

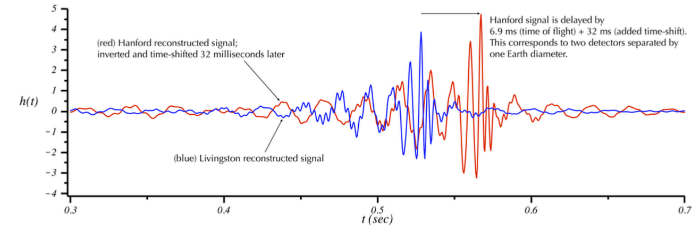
- An audio exploration of the physics of gravitational-wave signals.
- Explain what physical effects influence the gravitational wave signal [showing h(t) plots and corresponding audio].
- Provide audio for all GW source types.
- Detailed pages for detected events.
- A tool for training students.



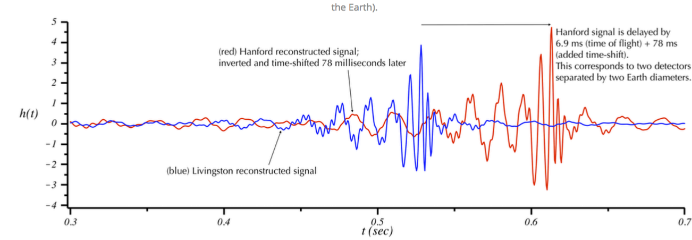
soundsofspacetime.org

Features to explore:

- effect of varying masses on circular inspiral.
- effect of higher harmonics.
- effect of varying eccentricity and turning periastron advance on/off.
- effect of varying spin; turning precession on/off.
- effect of including merger/ringdown.
- stereo audio for all detections including: raw data, filtered data, template.
- effect of time-of-flight (left ear/right ear).
- comparison of 4 GW events.
- illustration of phase shift from Lorentz violation.
- coming soon: NS spin-down, supernovae, stochastic background.



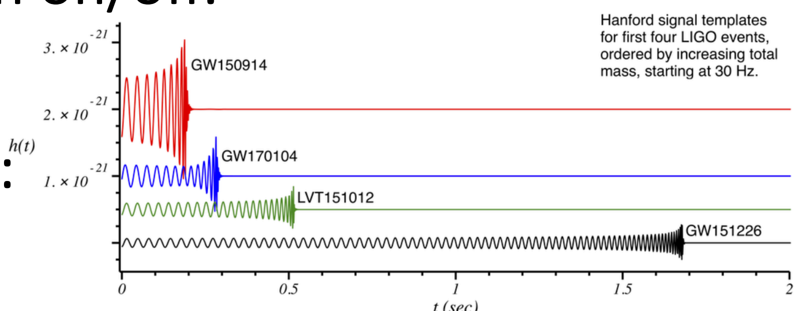
Similar to the above two plots except an additional time-shift has been added to the Hanford signal (corresponding to two detectors on opposite sides of the Earth).



Same as above except a time-shift of 78 milliseconds was added to the Hanford signal corresponding to two detectors separated by two Earth diameters.

Stereo sound corresponding to the top plot above. The Hanford signal is time shifted to model the effect of two detectors on opposite sides of the Earth. (Headphones or good speakers recommended.)

Stereo sound corresponding to two detectors separated by two Earth diameters. One can clearly hear the sound in the right ear, followed by the sound in the left. (Headphones or good speakers recommended.)



anford waveform models for all LIGO events so far, ordered by increasing total mass (lower masses on bottom). [Data courtesy of Ben Farr and the LIGO team.]

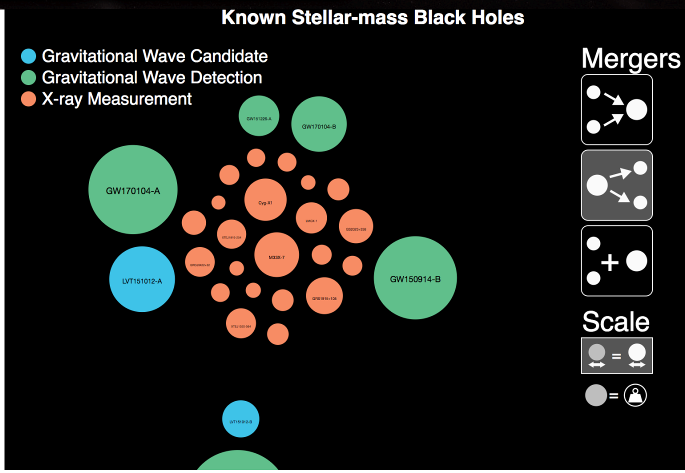
Stereo audio of first four LIGO events in order of decreasing mass: GW150914, GW170104, LVT151012, GW151226. Signal starts at 30 Hz. Volume is scaled in proportion to signal amplitude. (Hanford/left, Livingston/right; headphones or good speakers recommended.)

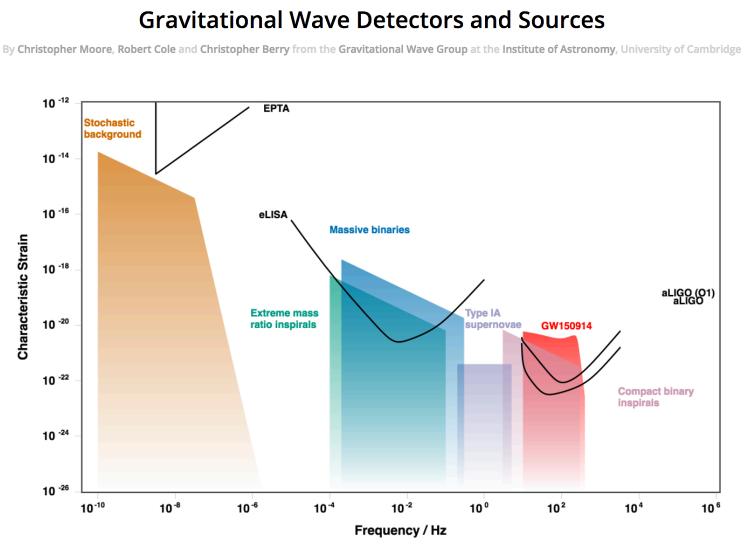
other interactive websites

- *gravoscope*
  interactive skymap (Cardiff U.)
  http://astrog80.astro.cf.ac.uk/Gravoscope/

- Known BH Masses
  interactive figure (Cardiff U.)
  https://gravity.astro.cf.ac.uk/plotgw/bhbubble.html

- GW sensitivity curve plotter
  (U. Cambridge)
  http://rhcole.com/apps/GWplotter/

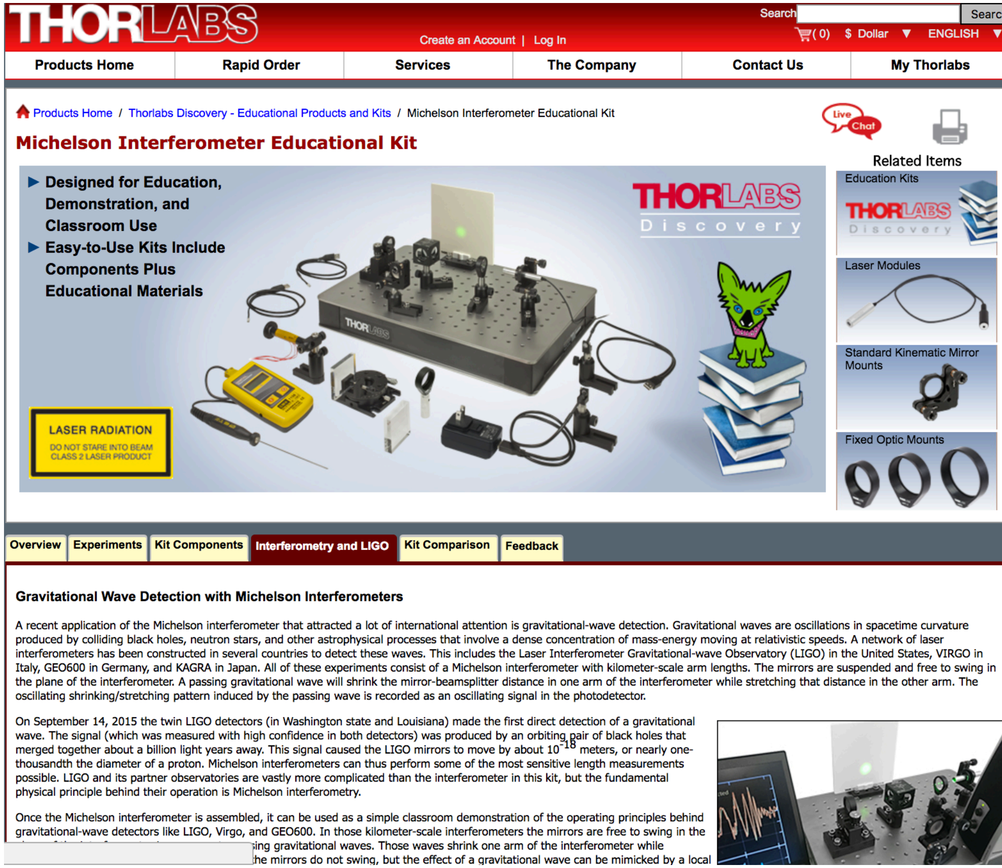




Thorlabs collaboration

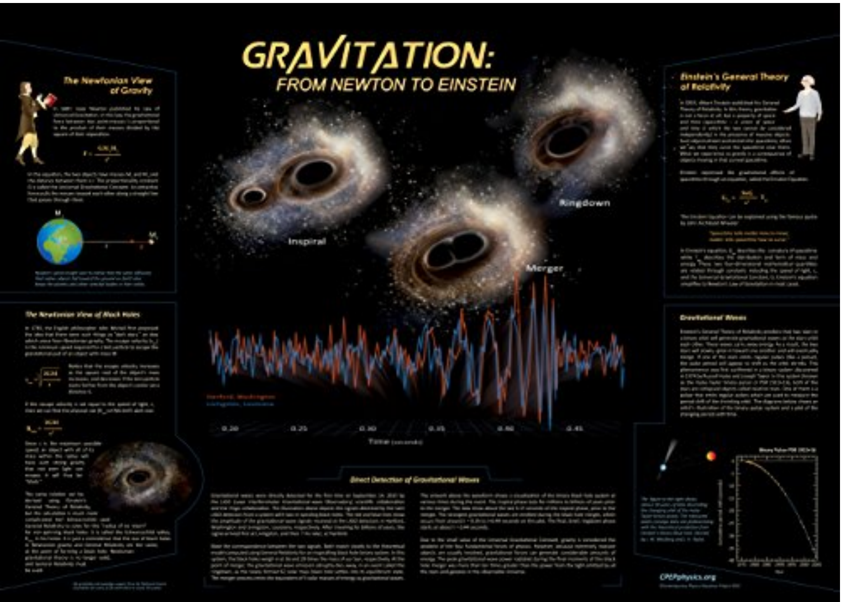
- Developed Michelson interferometer kit; sturdy, high-quality ($2648). Good for upper-level undergrad lab courses. Contributed discussion of LIGO to product manual.
  https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=10107

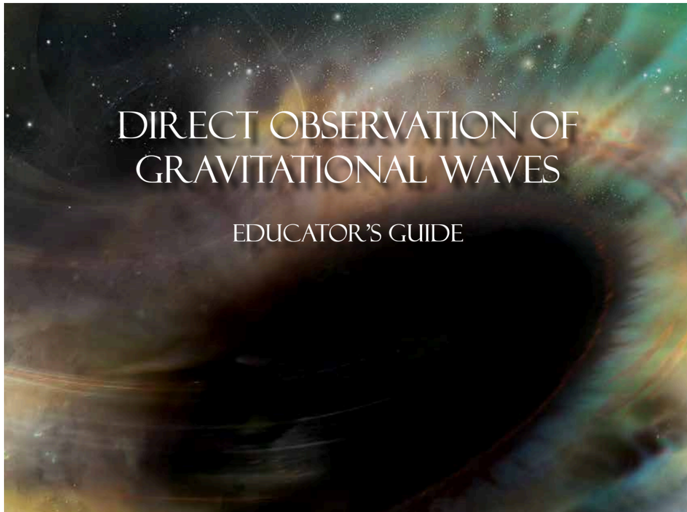
- future work: LSC members working with Thorlabs to develop lower-cost demo interferometer (<$500), as well as more advanced add-ons for the existing Michelson kit.



Online courses on GWs

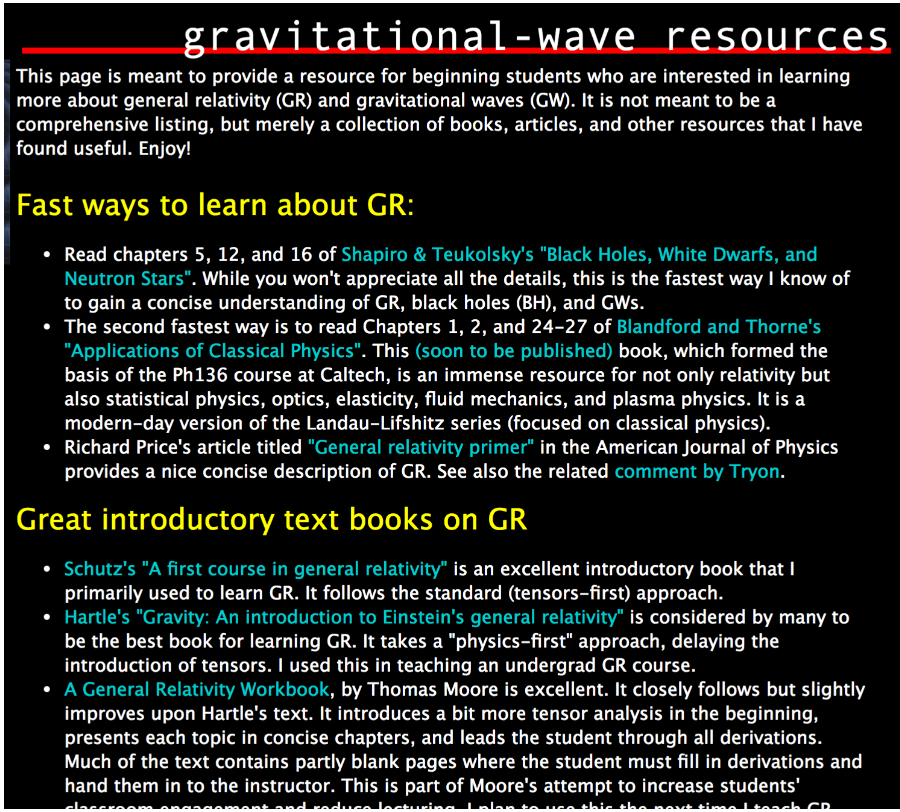
- developed by Lynn Cominsky and collaborators at Sonoma State Univ; https://universe.sonoma.edu/cosmo/
- lecture notes + exercises.
- good for training undergrads in GWs.
- also educator's guide (for ~middle school); https://dcc.ligo.org/LIGO-P1600015/public
- Gravitation poster for CPEP (Contemporary Physics Education Project); http://www.cpepweb.org/





Resource collections

- www.astro.cornell.edu/~favata/gwresources.html
- www.astro.cornell.edu/~favata/outreach.html
- wiki.ligo.org/LAAC/WebHome
- ligo.org/detections.php
- coming soon: new resource letter on gravitational waves in American Journal of Physics



gravitational-wave resources

This page is meant to provide a resource for beginning students who are interested in learning more about general relativity (GR) and gravitational waves (GW). It is not meant to be a comprehensive listing, but merely a collection of books, articles, and other resources that I have found useful. Enjoy!

Fast ways to learn about GR:

- Read chapters 5, 12, and 16 of Shapiro & Teukolsky's "Black Holes, White Dwarfs, and Neutron Stars". While you won't appreciate all the details, this is the fastest way I know of to gain a concise understanding of GR, black holes (BH), and GWs.
- The second fastest way is to read Chapters 1, 2, and 24-27 of Blandford and Thorne's "Applications of Classical Physics". This (soon to be published) book, which formed the basis of the Ph136 course at Caltech, is an immense resource for not only relativity but also statistical physics, optics, elasticity, fluid mechanics, and plasma physics. It is a modern-day version of the Landau-Lifshitz series (focused on classical physics).
- Richard Price's article titled "General relativity primer" in the American Journal of Physics provides a nice concise description of GR. See also the related comment by Tryon.

Great introductory text books on GR

- Schutz's "A first course in general relativity" is an excellent introductory book that I primarily used to learn GR. It follows the standard (tensors-first) approach.
- Hartle's "Gravity: An introduction to Einstein's general relativity" is considered by many to be the best book for learning GR. It takes a "physics-first" approach, delaying the introduction of tensors. I used this in teaching an undergrad GR course.
- A General Relativity Workbook, by Thomas Moore is excellent. It closely follows but slightly improves upon Hartle's text. It introduces a bit more tensor analysis in the beginning, presents each topic in concise chapters, and leads the student through all derivations. Much of the text contains partly blank pages where the student must fill in derivations and hand them in to the instructor. This is part of Moore's attempt to increase students'

Conclusions:

- LSC EPO group has been developing a wide variety of resources.

- Useful for informing the public, educating students (including undergrads), and providing resources for web and print media.

- **Suggestions for us?**
  What resources would you like to see developed?
  New ways to disseminate our materials?
  New audiences to reach?