LIGO Lab Outreach

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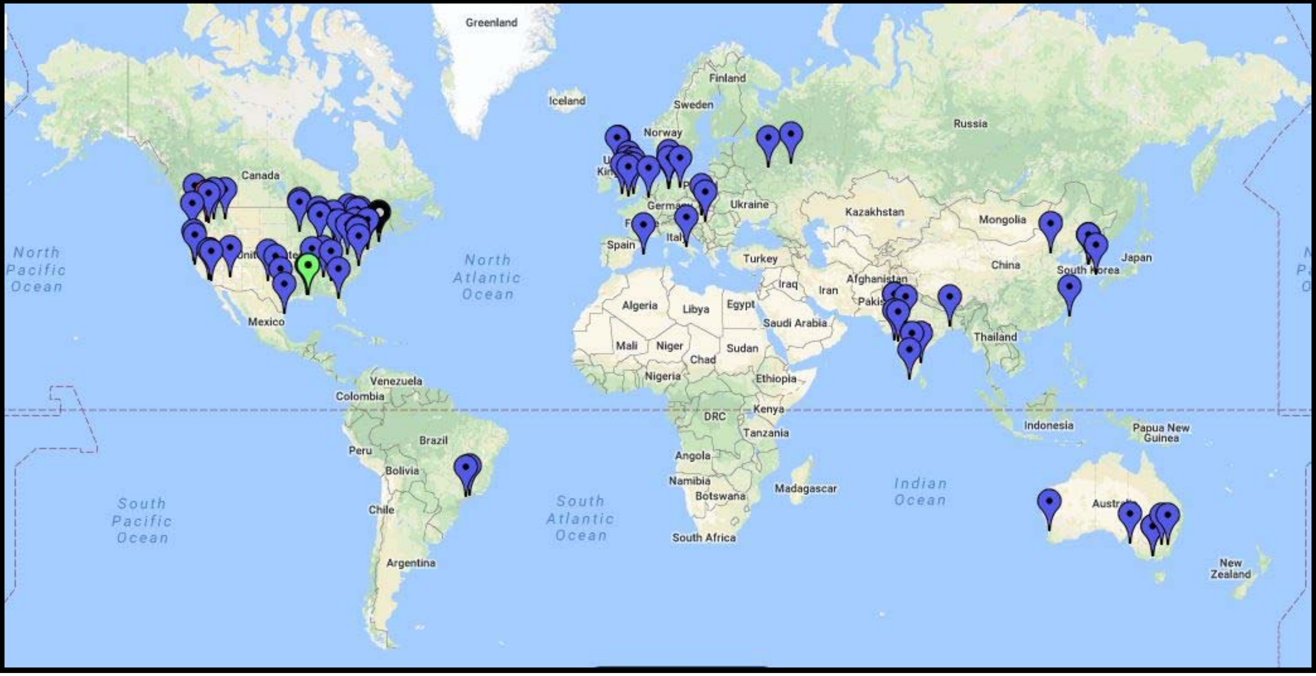
Lab vs Collaboration

- LIGO Lab
  - » Caltech
  - » MIT
  - » LIGO Hanford Observatory
  - » LIGO Livingston Observatory
- LIGO Scientific Collaboration
  - » 1200+ Scientist
  - » 108 Institutions
  - » 18 Countries

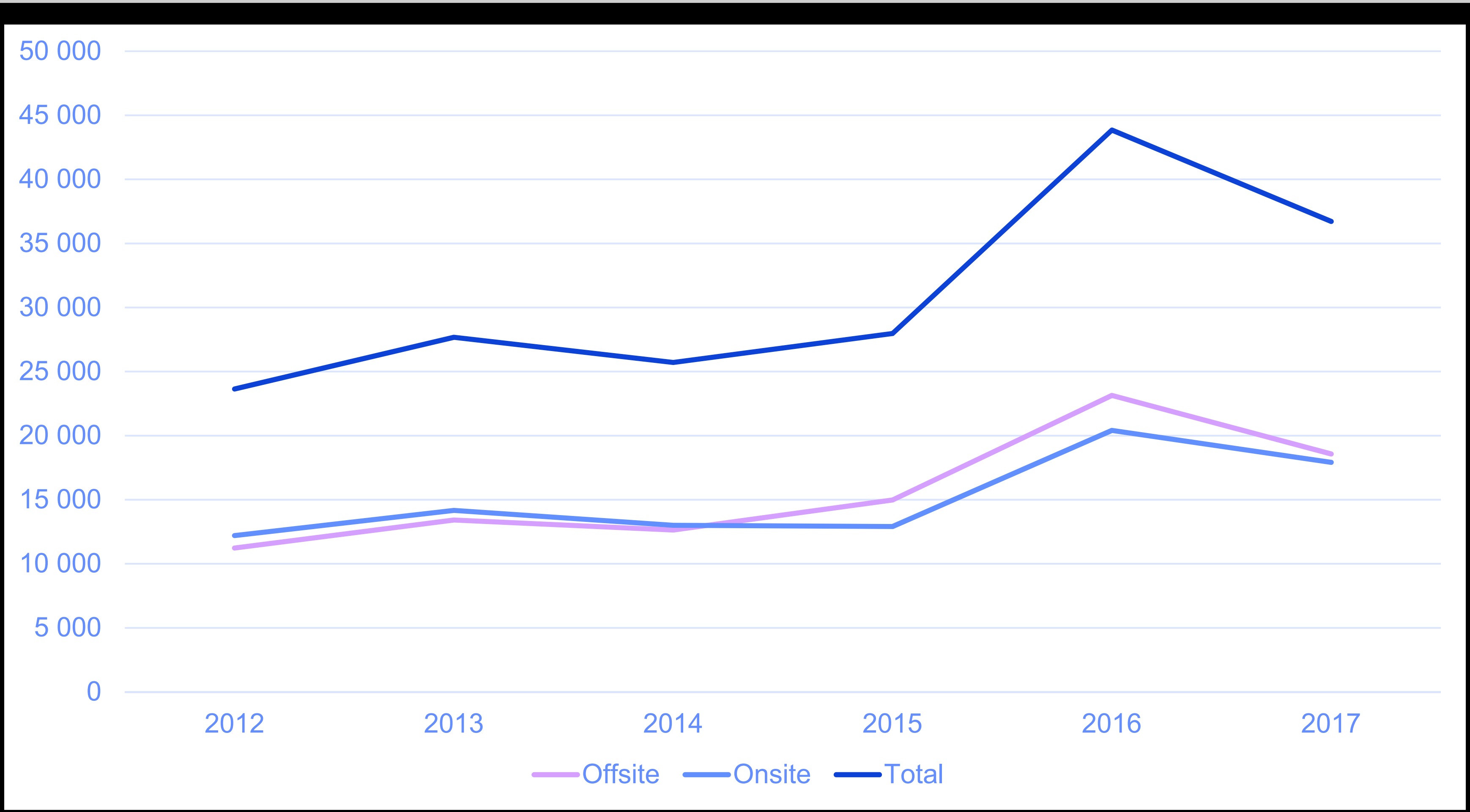


Type of Outreach

- Offsite
  - » Classroom Visits
  - » Science Nights
  - » Public Talks
  - » Community Groups
  - » Virtual Visits
  - » Educational Conferences
  - » Social Media
    - – Twitter @LIGOWA @LIGOLA
    - – Facebook
- Onsite
  - » K-12 Field Trips
  - » University Tours
  - » Private Tours
  - » Public Open Days
  - » Special Events
  - » Teacher Professional Development

World Wide Reach

Outreach Growth 2012-2017

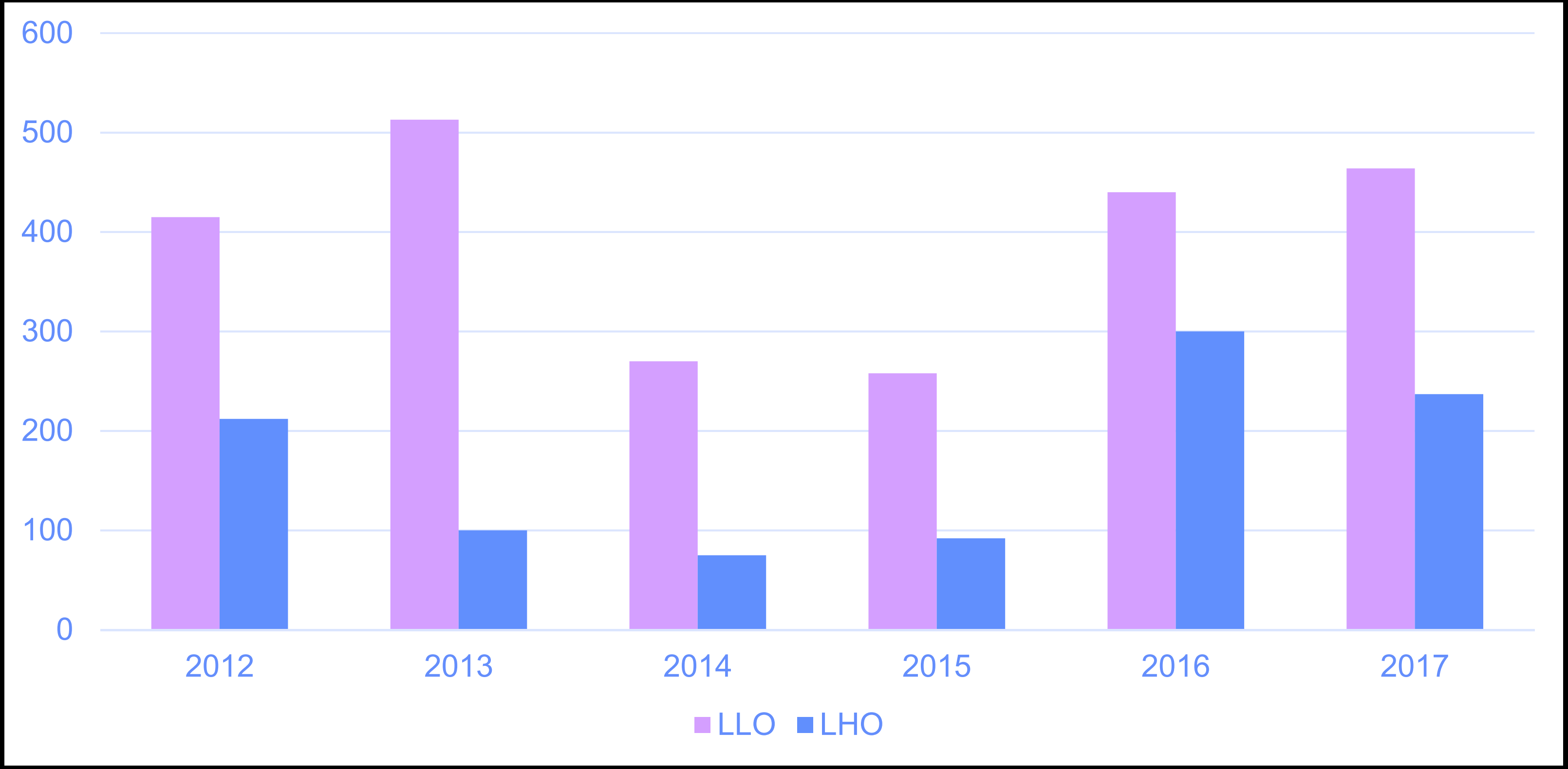


"My son may be six years-old, but the LIGO observatory is his favorite place in the world."

"I have been teaching for 35 years and have been on quite a lot of field trips, but LIGO is by far the best."

"Awesome yesterday to see how many women are in senior science positions at @LIGOWA it was super inspirational to my daughter, a freshman physics major."

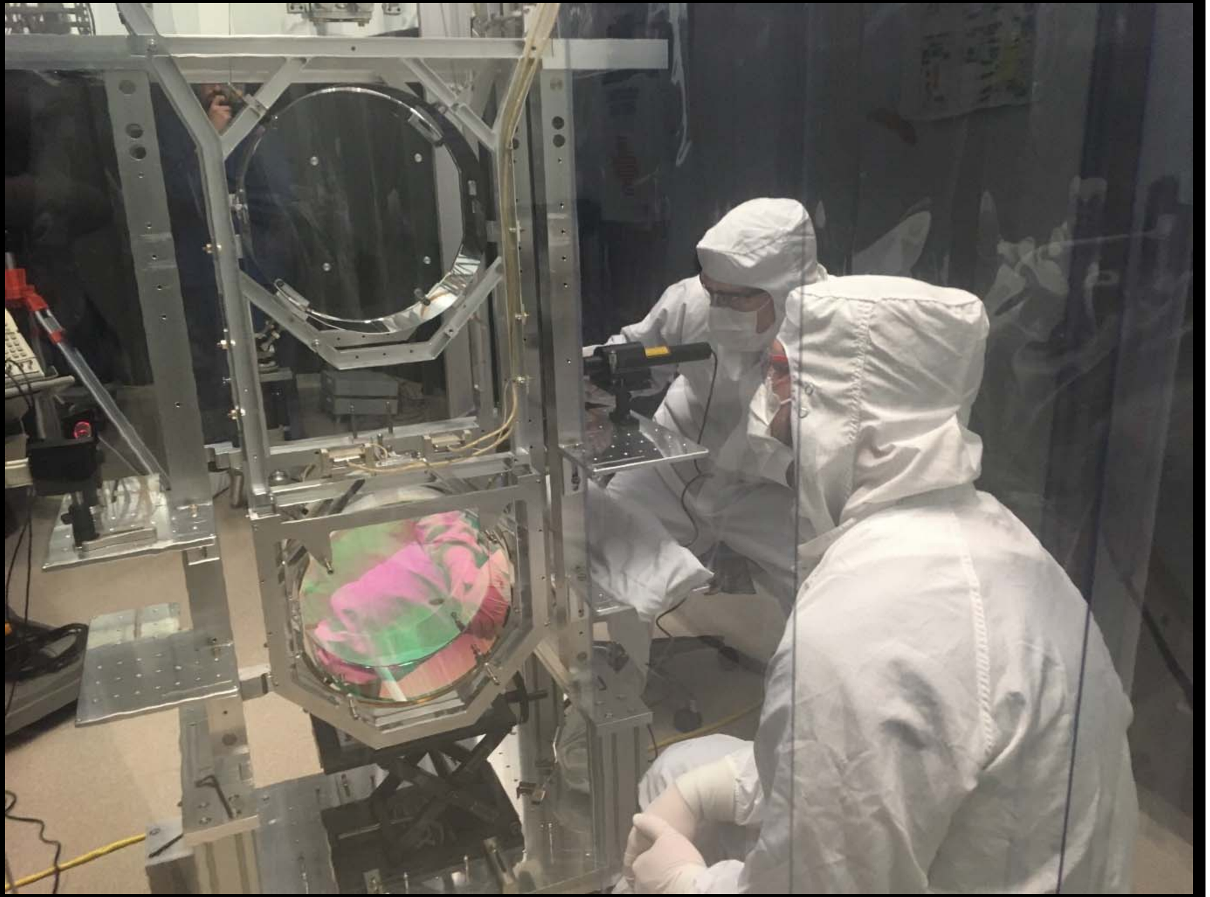
Teacher Professional Development



3,376 Teachers
~168,800 Students impacted

LIGO Connections to High School Physics

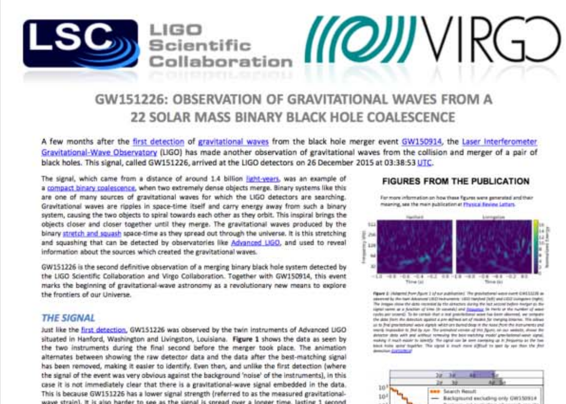
- Gravity
- Waves
  - » Interference
  - » Resonance
  - » Sound
  - » Light
- Optics
- Simple Harmonic Motion
  - » Pendulums



EPO Activities of the LSC

Martin Hendry, Univ of Glasgow

For the LSC EPO group

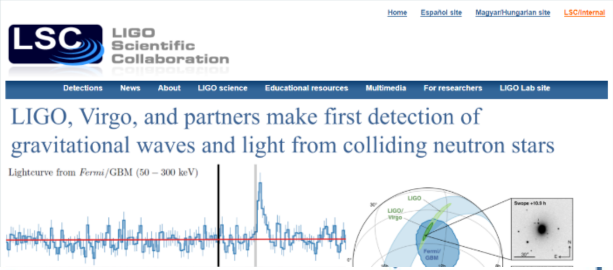

GW151226: OBSERVATION OF GRAVITATIONAL WAVES FROM A 22 SOLAR MASS BINARY BLACK HOLE COALESCENCE

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.

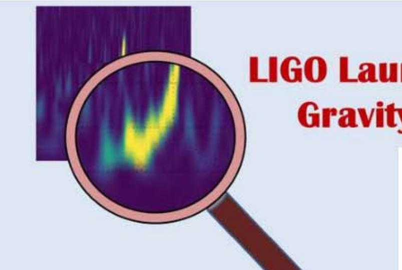
The signal, which came from a distance of around 1.4 billion light-years, was an example of a compact binary coalescence, when two extremely dense objects merge. Binary systems like this are one of many sources of gravitational waves for which the LIGO detectors are searching. Gravitational waves are 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.

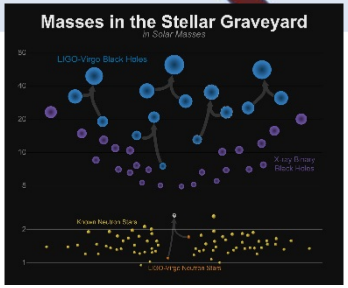
FIGURES FROM THE PUBLICATION

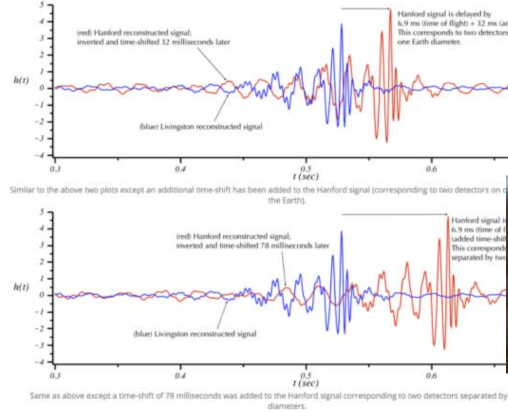
THE SIGNAL



LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars







Similar to the above two plots except an additional time-shift has been added to the Hanford signal (corresponding to two detectors on o

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.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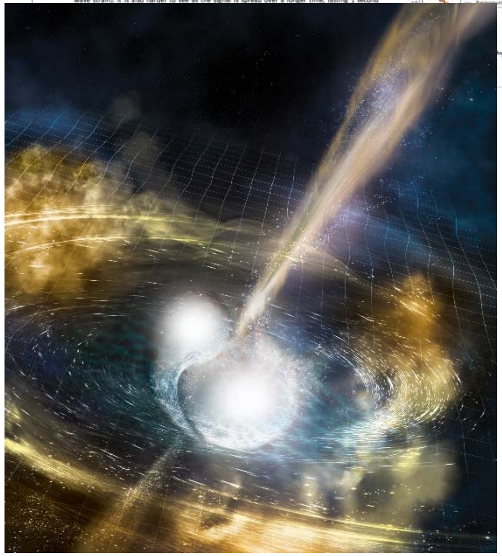
Gabriela Gonzalez
Professor at Louisiana State University
Former LSC Spokesperson



LIGO Scientific Collaboration

Abilene Christian University
Albert-Einstein-Institut
American University
Andrews University
Bellevue College
California Institute of Technology
California State Univ., Fullerton
California State Univ., Los Angeles
Canadian Inst. Th. Astrophysics
Carleton College
Chinese University of Hong Kong
College of William and Mary
Colorado State University
Columbia U. in the City of New York
Cornell University
Embry-Riddle Aeronautical Univ.
Eötvös Loránd University
Georgia Institute of Technology
Goddard Space Flight Center
GW-INPE, Sao Jose Brasil
Hillsdale College
Hobart & William Smith Colleges
IAP – Nizhny Novogorod
IIP-UFRN
Kenyon College
Korean Gravitational-Wave Group
Louisiana State University
Marshall Space Flight Center
Montana State University
Montclair State University
Moscow State University
National Tsing Hua University
NCSARG – Univ. of Illinois, Urbana-Champaign

Northwestern University
Penn State University
Rochester Institute of Technology
Sonoma State University
Southern University
Stanford University
Syracuse University
Texas Tech University
Trinity University
Tsinghua University
U. Montreal / Polytechnique
Université Libre de Bruxelles
University of Chicago
University of Florida
University of Maryland
University of Michigan
University of Minnesota
University of Mississippi
University of Oregon
University of Sannio
University of Szeged
University of Texas Rio Grande Valley
University of the Balearic Islands
University of Tokyo
University of Washington
University of Washington Bothell
University of Wisconsin – Milwaukee
USC – Information Sciences Institute
Villanova University
Washington State University – Pullman
West Virginia University
Whitman College

LIGO Laboratory: California Institute of Technology; Massachusetts Institute of Technology;
LIGO Hanford Observatory; LIGO Livingston Observatory

Australian Consortium for Interferometric Gravitational Astronomy (ACIGA):
Australian National University; Charles Sturt University; Monash University; Swinburne University; University of Adelaide; University of Melbourne; University of Western Australia

German/British Collaboration for the Detection of Gravitational Waves (GEO600):
Albert-Einstein-Institut, Hannover; Cardiff University; King's College, University of London; Leibniz Universität, Hannover; University of Birmingham; University of Cambridge; University of Glasgow; University of Hamburg; University of Sheffield; University of Southampton; University of Strathclyde; University of the West of Scotland; University of Zurich

Indian Initiative in Gravitational-Wave Observations (IndIGO):
Chennai Mathematical Institute; ICTS-TIFR Bangalore; IISER Pune; IISER Kolkata; IISER-TVM Thiruvananthapuram; IIT Madras, Chennai; IIT Kanpur;
IIT Gandhinagar; IPR Bhatt; IUCAA Pune; RRCAT Indore; University of Delhi

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)

Goals:

- Communicate LIGO science
- Improve general scientific literacy
- Increase STEM recruitment and participation
- Support community of citizen scientists

10 years of EPO

- < 50% of LSC groups with an EPO MoU
- Highly active programs at **LHO**, **LLO** and **Virgo**
- Vast range of EPO activities across the globe:

Formal Education

- Formal Education Unit inspired by LIGO
- Teacher professional development
- Partnerships with existing classroom networks
- GW Masterclasses for high school students

Informal Education & Public Outreach

- **Visual and web media**; audio and multimedia
- **Social media**
- Computer and board games, apps, software tools
- **Citizen Science projects**
- **Exhibits**
- **Printed materials**
- Connections to art, theater and dance
- Multilingual outreach
- Outreach to children
- Public lectures

Higher Education

- In person faculty professional development
- On-line teacher professional development
- Resources for college faculty and students
- Talks and lectures
- Summer research programs

Professional Outreach

- **Outreach to other scientists**
- Outreach to the broader academic community, including funding agencies and/or foundations
- Outreach to government and legislative officials

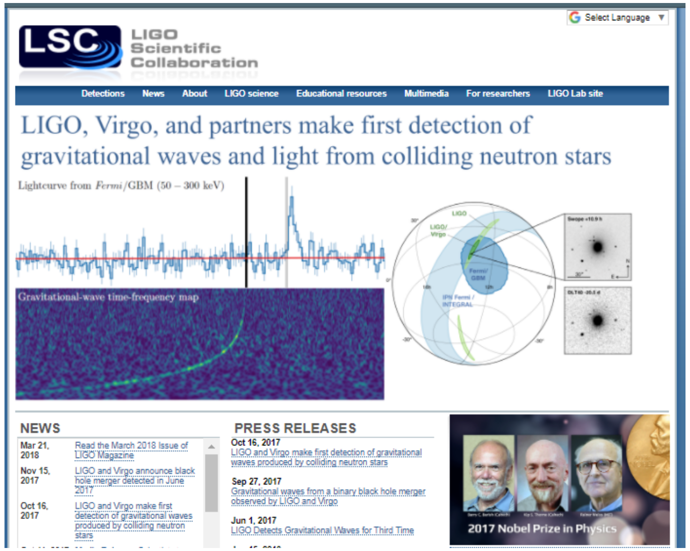
__Way__ too many highlights to showcase, in detail but will pick out a few highlights

ligo.org

LSC's main global communication tool.

Key products:

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



LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars

NEWS

Mar 21, 2018 Read the March 2018 Issue of LIGO Magazine

Nov 15, 2017 LIGO and Virgo announce black hole merger detected in June 2017

Oct 16, 2017 LIGO and Virgo make first detection of gravitational waves produced by colliding neutron stars

PRESS RELEASES

Oct 16, 2017
LIGO and Virgo make first detection of gravitational waves produced by colliding neutron stars

Sep 27, 2017
Gravitational waves from a binary black hole merger observed by LIGO and Virgo

Jun 1, 2017
LIGO Detects Gravitational Waves for Third Time

DETECTIONS

Information about gravitational-wave detections made by LIGO to date.

Jump to a separate page for a specific event (listed in reverse-chronological order), or see the General Detection Resources section below for further information on LIGO detections.

- GW170608
- GW170817 (First binary neutron star detection; first electromagnetic counterpart)
- GW170814
- GW170104
- GW151226
- GW150914 (First detection)

GENERAL DETECTION RESOURCES

DOCUMENTS, WEBSITES, & MULTIMEDIA

- Full list of LSC Publications. (See Runs O1 and higher for papers following the first detection.)
- Science Summaries
- LIGO Open Science Center (LOSC): Download LIGO data or explore tutorials on LIGO data analysis. See also their data release page for links to audio of LIGO events.
- Timeline and brief history of the LIGO project.
- The Caltech Media Assets page for GW150914 contains a wealth of useful documents, graphics, and video.
- Sounds of Spacetime: A website that explains LIGO detections and gravitational-wave physics via the analogy between gravitational waves and audio signals. (Montclair State University)
- Black Hole Bubble Diagram: Interactive graphics showing known stellar-mass black holes from gravitational-wave candidates and X-ray binaries. (Cardiff University School of Physics and Astronomy)
- LIGO Gravoscope: An interactive tool that lets you compare visions of the Universe in a range of wavelengths. Also shows locations of detected gravitational-wave signals. (Cardiff University Astronomy and Astronomy Instrumentation Groups)
- Gravity Spy: a citizen-science project to help LIGO search for gravitational waves by improving glitch classification.
- Einstein@Home: use your computer's idle processing time to help search for pulsars using gravitational wave, radio, and gamma-ray data.
- Educator's Guide: Contains background material on gravitational waves and classroom activities that align with K-12 science standards. (Sonoma State University)
- Image gallery hosted at the LIGO Lab site.
- LSC Youtube Channel, Facebook page, and Twitter page.
- "Chirp" ringtones from the first two LIGO detections. (Instructions). GW150914 [m4r file (iPhone) | mp3 file (Android)]; GW151226 [m4r file (iPhone) | mp3 file (Android)]

GW150914 signal observed by the twin LIGO observatories at Livingston, Louisiana, and Hanford, Washington. The signals came from two merging black holes, each about 30 times the mass of our sun, lying 1.3 billion light-years away. The top two plots show data received at Livingston and Hanford, along with the predicted shapes for the waveform. These predicted waveforms show what two merging black holes should look like according to the equations of Albert Einstein's general theory of relativity, along with the instrument's ever-present noise. Time is plotted on the X-axis and strain on the Y-axis.

New Population of Binary Black Holes. LIGO and Virgo have discovered a new population of black holes with masses that are larger than what had been seen before with X-ray studies alone (purple). The three previously confirmed detections by LIGO (GW150914, GW151226, GW170104,) plus one lower-confidence detection (LVT151012), are shown along with the fourth confirmed detection (GW170814); the latter was observed by Virgo and both LIGO observatories. These point to a population of stellar-mass binary black holes that, once merged, are larger than 20 solar masses—larger than what was known before. [Image credit: LIGO/Caltech/Sonoma State (Aurore Simonnet)]

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.
- **More than 80 summaries since 2011**
- Now core part of PWT responsibilities, assisted by EPO group

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

GW170608 (Nov 13, 2017) **Detection paper:**

GW170608: LIGO's Lightest Black Hole Binary? [flyer]

Also in French.

GW170817 (Oct 16, 2017) **Detection paper:**

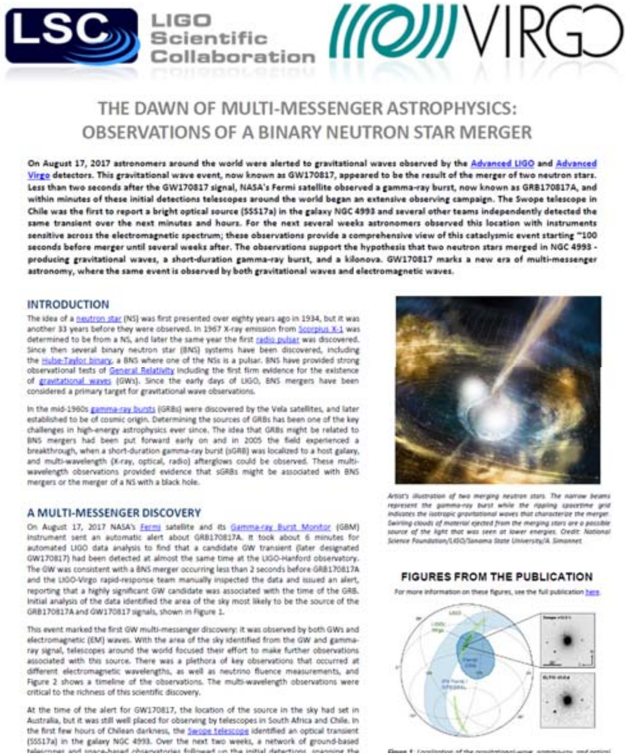
GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral [flyer]

Also in Chinese | French | German | Russian | Spanish.

Companion papers (listed alphabetically; more summaries will appear here soon):

- The Dawn of Multi-Messenger Astrophysics: Observations of a Binary Neutron Star Merger [flyer] Also available in other languages.
- Gravitational waves and Gamma-Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A [flyer] Also available in other languages.
- Measuring the Expansion of the Universe with Gravitational Waves [flyer] Also available

LOOKING DOWN A DETECTOR ARM



THE DAWN OF MULTI-MESSENGER ASTROPHYSICS: OBSERVATIONS OF A BINARY NEUTRON STAR MERGER

On August 17, 2017 astronomers around the world were alerted to gravitational waves observed by the Advanced LIGO and Advanced Virgo detectors. This gravitational wave event, now known as GW170817, appeared to be the result of the merger of two neutron stars. Less than two seconds after the GW170817 signal, NASA's Fermi satellite observed a gamma-ray burst, now known as GRB170817A, and within minutes of these initial detections telescopes around the world began an extensive observing campaign. The Swope telescope in Chile was the first to report a bright optical source (SSS17a) in the galaxy NGC 4993 and several other teams independently detected the same transient over the next minutes and hours. For the next several weeks astronomers observed this location with instruments sensitive across the electromagnetic spectrum; these observations provide a comprehensive view of this cataclysmic event starting ~100 seconds before merger until several weeks after. The observations support the hypothesis that two neutron stars merged in NGC 4993 - producing gravitational waves, a short-duration gamma-ray burst, and a kilonova. GW170817 marks a new era of multi-messenger astronomy, where the same event is observed by both gravitational waves and electromagnetic waves.

INTRODUCTION

The idea of a neutron star (NS) was first presented over eighty years ago in 1934, but it was another 33 years before they were observed. In 1967 X-ray emission from Scorpius X-1 was determined to be from a NS, and later the same year the first radio pulsar was discovered. Since then several binary neutron star (BNS) systems have been discovered, including the Hulse-Taylor binary, a BNS where one of the NSs is a pulsar. BNS have provided strong observational tests of General Relativity including the first firm evidence for the existence of gravitational waves (GWs). Since the early days of LIGO, BNS mergers have been considered a primary target for gravitational wave observations.

In the mid-1960s gamma-ray bursts (GRBs) were discovered by the Vela satellites, and later established to be of cosmic origin. Determining the sources of GRBs has been one of the key challenges in high-energy astrophysics ever since. The idea that GRBs might be related to BNS mergers had been put forward early on and in 2005 the field experienced a breakthrough, when a short-duration gamma-ray burst (sGRB) was localized to a host galaxy, and multi-wavelength (X-ray, optical, radio) afterglows could be observed. These multi-wavelength observations provided evidence that sGRBs might be associated with BNS mergers or the merger of a NS with a black hole.

Artist's illustration of two merging neutron stars. The narrow beams represent the gamma-ray burst while the rippling spacetime grid indicates the isotropic gravitational waves that characterize the merger. Swirling clouds of material ejected from the merging stars are a possible source of the light that was seen at lower energies. Credit: National Science Foundation/LIGO/Sonoma State University/A. Simonnet.

A MULTI-MESSENGER DISCOVERY

On August 17, 2017 NASA's Fermi satellite and its Gamma-ray Burst Monitor (GBM) instrument sent an automatic alert about GRB170817A. It took about 6 minutes for automated LIGO data analysis to find that a candidate GW transient (later designated GW170817) had been detected at almost the same time at the LIGO-Hanford observatory. The GW was consistent with a BNS merger occurring less than 2 seconds before GRB170817A and the LIGO-Virgo rapid-response team manually inspected the data and issued an alert, reporting that a highly significant GW candidate was associated with the time of the GRB. Initial analysis of the data identified the area of the sky most likely to be the source of the GRB170817A and GW170817 signals, shown in Figure 1.

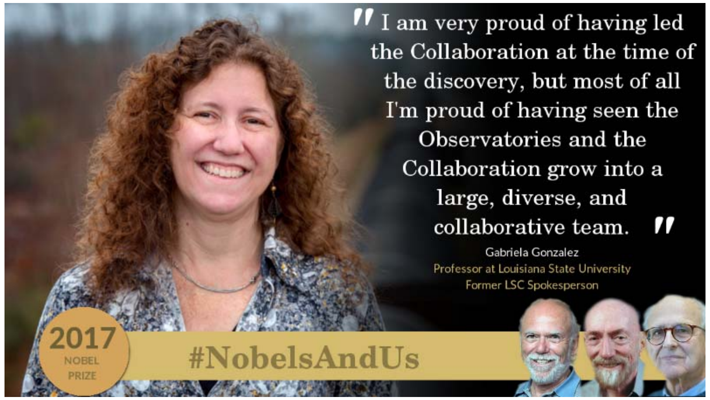
This event marked the first GW multi-messenger discovery: it was observed by both GWs and electromagnetic (EM) waves. With the area of the sky identified from the GW and gamma-ray signal, telescopes around the world focused their effort to make further observations associated with this source. There was a plethora of key observations that occurred at different electromagnetic wavelengths, as well as neutrino fluence measurements, and Figure 2 shows a timeline of the observations. The multi-wavelength observations were critical to the richness of this scientific discovery.

At the time of the alert for GW170817, the location of the source in the sky had set in Australia, but it was still well placed for observing by telescopes in South Africa and Chile. In the first few hours of Chilean darkness, the Swope telescope identified an optical transient (SSS17a) in the galaxy NGC 4993. Over the next two weeks, a network of ground-based

FIGURES FROM THE PUBLICATION

For more information on these figures, see the full publication here.

EPO Social Media:



> "I am very proud of having led the Collaboration at the time of the discovery, but most of all I'm proud of having seen the Observatories and the Collaboration grow into a large, diverse, and collaborative team."

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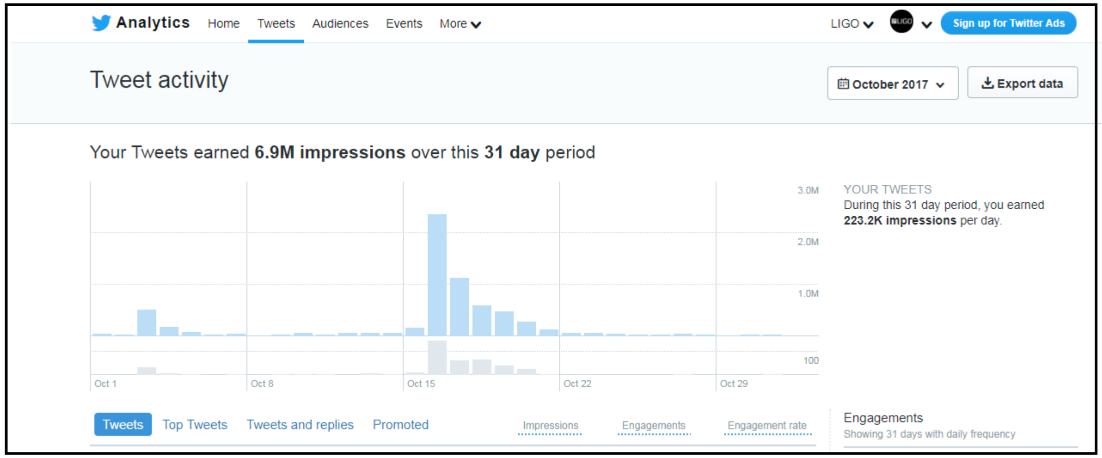
Professor at Louisiana State University
Former LSC Spokesperson



Tweet activity

Your Tweets earned **6.9M impressions** over this **31 day** period

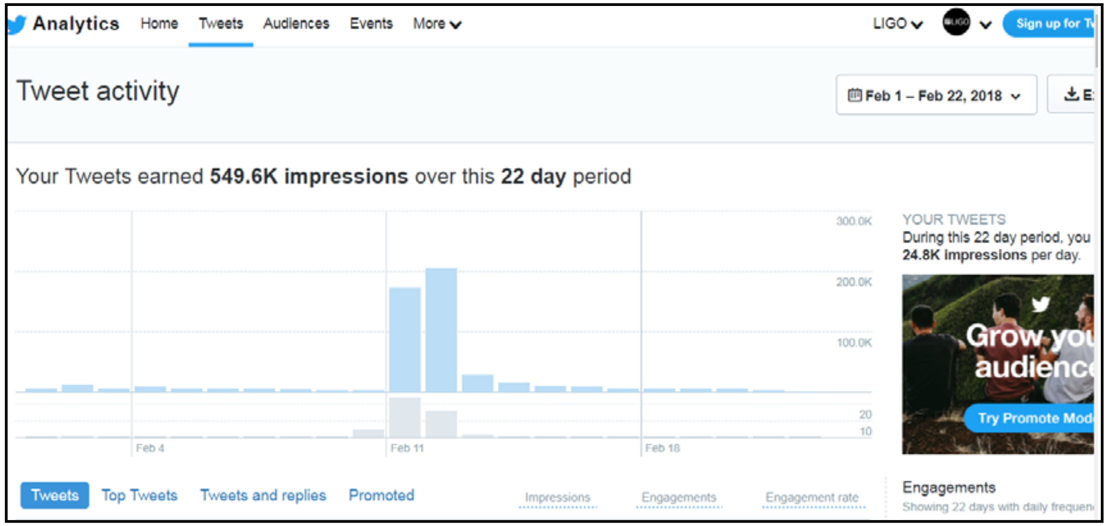
YOUR TWEETS
During this 31 day period, you earned **223.2K impressions** per day.

Engagements
Showing 31 days with daily frequency

Tweet activity

Your Tweets earned **1.3M impressions** over this **31 day** period

YOUR TWEETS
During this 31 day period, you earned **41.9K impressions** per day.



Tweet activity

Your Tweets earned **549.6K impressions** over this **22 day** period

YOUR TWEETS
During this 22 day period, you
24.8K impressions per day.

Engagements
Showing 22 days with daily frequen

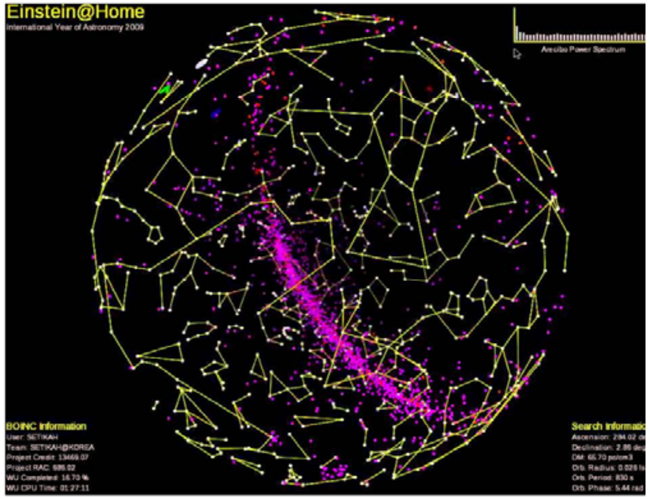
Aiming to improve social media coordination with laboratories, institutions, consortia and other GW projects.

Thinking hard about how best to support O3 public alerts

Citizen science: Einstein@home

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

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



User: SETIKAH
Team: SETIKAH@KOREA
Project Credit: 13469.07
Project RAC: 686.02
WU Completed: 16.70 %
WU CPU Time: 01:27:11

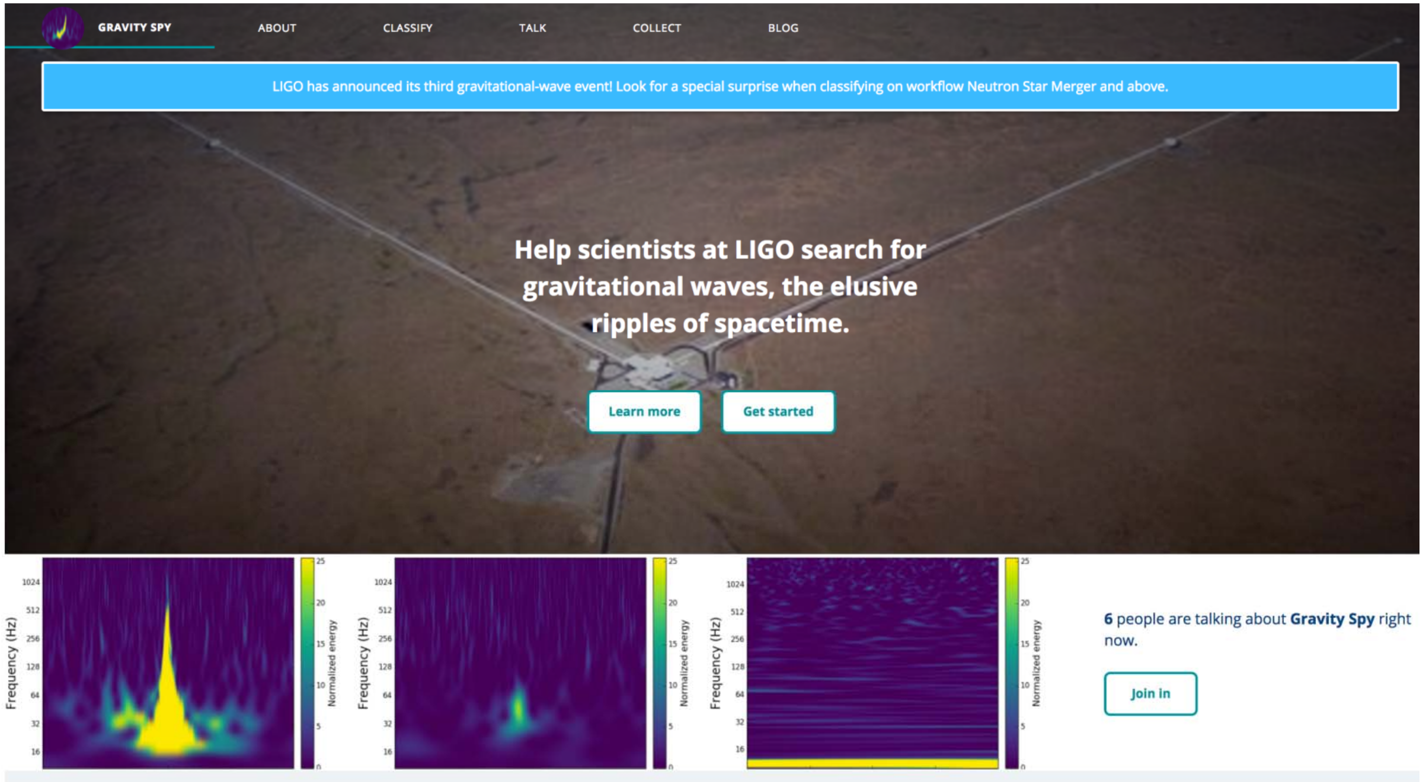
Ascension: 284.02 de
Declination: 2.86 deg
DM: 65.70 pc/cm3
Orb. Radius: 0.026 ls
Orb. Period: 830 s
Orb. Phase: 5.44 rad

- 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. (Aug 2017)
- currently using O2 data.



LIGO has announced its third gravitational-wave event! Look for a special surprise when classifying on workflow Neutron Star Merger and above.

Help scientists at LIGO search for gravitational waves, the elusive ripples of spacetime.

6 people are talking about **Gravity Spy** right now.

LIGO Open Science Center (LOSC)

Main public portal
for LIGO data:

https://losc.ligo.org/

LIGO Open Science Center

LIGO is operated by California Institute of Technology and Massachusetts Institute of Technology and supported by the U.S. National Science Foundation.

Welcome to the LIGO Open Science Center

About LIGO
Get Started with LIGO data
Join the E-mail list for updates
For general information on LIGO, please visit ligo.org
If you have LSC credentials, you may go to the development site

Discoveries from the LIGO detectors!

released 2017 June 1:
Event of January 4, 2017: GW170104: total mass 50

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

Open F2F workshop in March 2018

LIGO Exhibits

2009: ~$1M NSF Grant for large and small travelling exhibition.

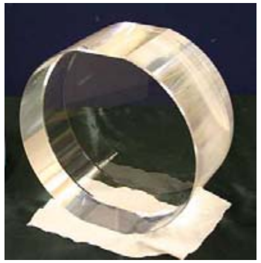
- Featured at WSF, USA SEF, exhibited at many US venues
- Not well-suited to “pop up” events: even the small version takes ~3 hours to assemble!...

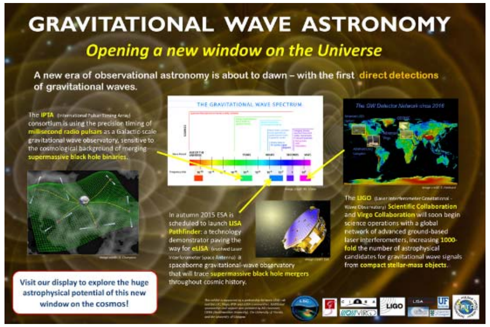
Visit our exhibition website at

http://ligo.phy.olemiss.edu/LIGOexhibit/

LIGO Exhibits

Recent focus on greater **flexibility** and **scalability** – creating easily portable exhibit resources to be **used / shared** across collaboration





GRAVITATIONAL WAVE ASTRONOMY

Opening a new window on the Universe

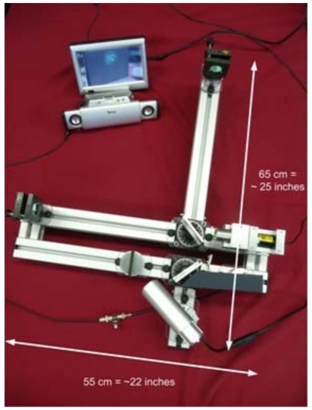
A new era of observational astronomy is about to dawn – with the first direct detections of gravitational waves.

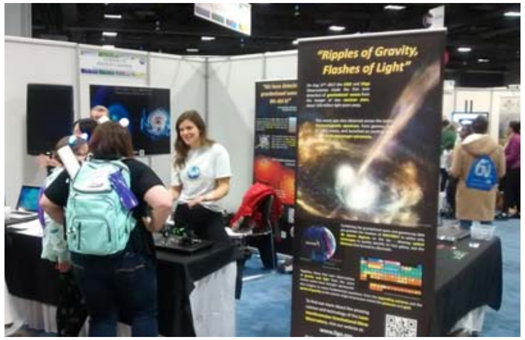
The IPTA (International Pulsar Timing Array) consortium is using the precision timing of millisecond radio pulsars as a Galactic-scale gravitational wave observatory, sensitive to the cosmological background of merging supermassive black hole binaries.

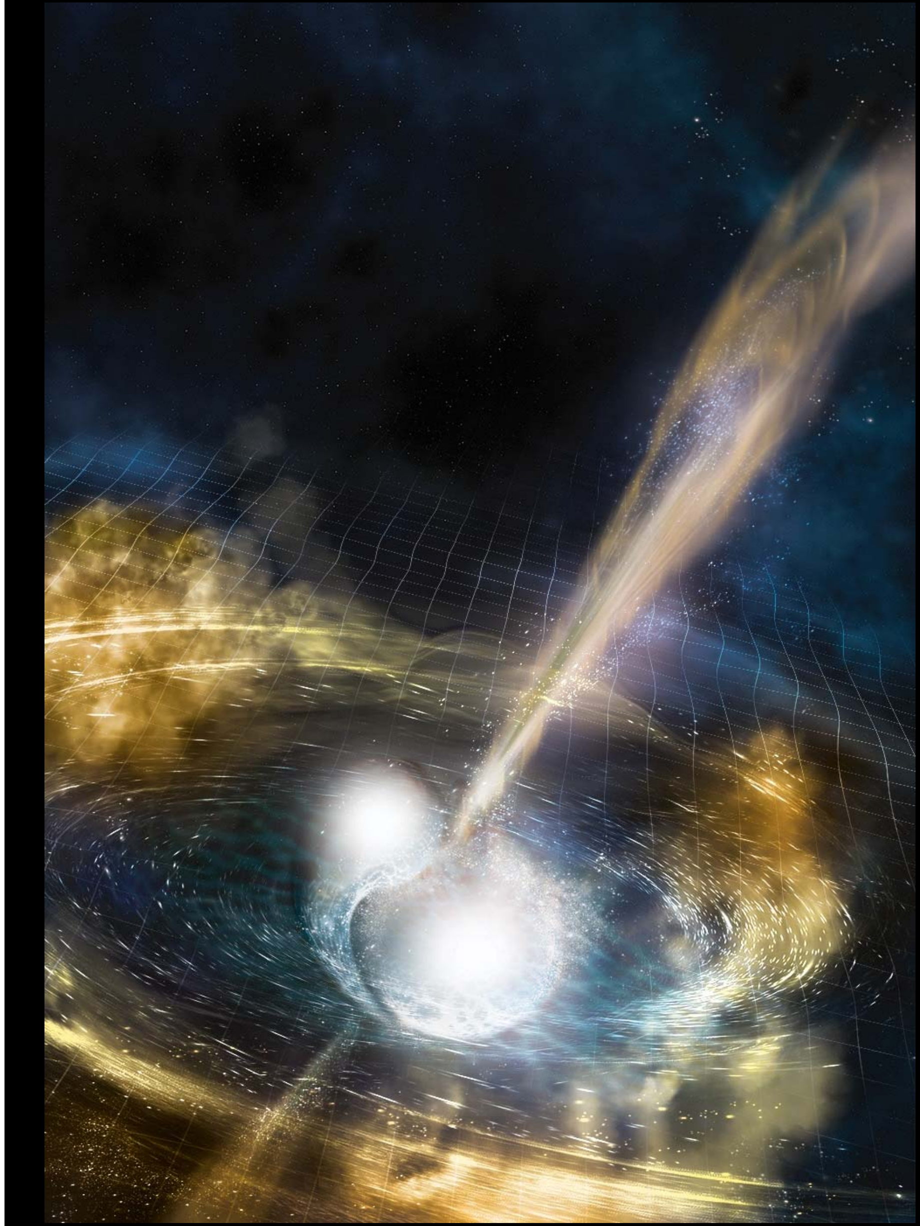
In autumn 2015 ESA is scheduled to launch LISA Pathfinder: a technology demonstrator paving the way for eLISA (evolved Laser Interferometer Space Antenna): a spaceborne gravitational-wave observatory that will trace supermassive black hole mergers throughout cosmic history.

The LIGO (Laser Interferometer Gravitational-Wave Observatory) Scientific Collaboration and Virgo Collaboration will soon begin science operations with a global network of advanced ground-based laser interferometers, increasing 1000-fold the number of astrophysical candidates for gravitational wave signals from compact stellar-mass objects.

Visit our display to explore the huge astrophysical potential of this new window on the cosmos!





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