“Observation of Gravitational Waves from a Binary Black Hole Merger”

LIGO: The Beginning of Gravitational-wave Astronomy*
(GW150914)

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Update:
Talk Outline

- Gravitational Waves and their detection by LIGO
- Southern University’s Role in LIGO
  ---- Optical Materials Science
  ----- Teacher Education and Science Literacy
- Current Work
- Summary and Future Activities
Scientific Mission of LIGO

• LIGO’s quest, ~400 yrs after invention of optical astronomical telescopes, is to create a radically new way to perceive the universe, by directly listening to the vibrations of space itself.

• LIGO consists of large, high-tech, earth-based, detectors that act like huge microphones, listening for “space quakes” created by the most violent events in the universe.
Newton's Gravitation

Newton's law: \( F = G \frac{m_1 m_2}{r^2} \)

Explains why things fall down, and planetary motion.
Einstein theorized that smaller masses travel toward larger masses, not because they are "attracted" by a mysterious force, but because the smaller objects travel through space that is warped by the larger object.

- Imagine space as a stretched rubber sheet.
- A mass on the surface will cause a deformation.
- Another mass dropped onto the sheet will roll toward that mass.

\[ G_{\mu\nu} = 8\pi T_{\mu\nu} \]
Laser Interferometer Gravitational-wave Observatory Sites

Funded by the National Science Foundation; operated by Caltech and MIT; the research focus for about 1000 LIGO Scientific Collaboration (LSC) members worldwide.
Astrophysical Sources of Gravitational Waves

Compact binary inspiral: \textit{“chirps”}
- NS-NS
- BH-BH

Supernovae / GRBs: \textit{“bursts”}
- burst signals in coincidence with signals in electromagnetic radiation
- prompt alarm (~ one hour) with neutrino detectors

Pulsars in our galaxy: \textit{“periodic signals”}
- search for observed neutron stars (frequency, doppler shift)
  - Einstein@home
- all sky search (computing challenge)
- r-modes

Cosmological Signals \textit{“stochastic background”}
WHAT EXACTLY ARE GRAVITATIONAL WAVES?
RIPPLES IN SPACE-TIME!
The first binary black-hole merger observed by LIGO: A Simulation

http://www.aei.mpg.de/1824987/?page=4

“Observation of Gravitational Waves from a Binary Black Hole Merger”
From Theory to Detection Timeline

~100 years ago: Albert Einstein published his theory of General Relativity, including the prediction of gravitational waves.

~50 years ago: Joseph Weber builds bar antennas to attempt detection of the waves.

~45 years ago: Key ideas for interferometric antennas developed by Rainer Weiss and others.

~40 years ago: NSF funding of pre-LIGO R&D.

~25 years ago: LIGO proposed to the NSF and approved. (1992)

~20 years ago: LIGO site construction began.

~18 years ago: McGuire began work with LIGO.

~5 years ago: Advanced LIGO installation began.
Gravitational Wave Detection
(Why did it take so long?)

Strain = $h = \frac{\delta L}{L}$

LIGO (4 km), stretch (squeeze) = $10^{-18}$ m will be detected at frequencies of 10 Hz to $10^4$ Hz.
How Small is $10^{-18}$ Meter?

- One meter, about 40 inches
- Human hair, about 100 microns
- Wavelength of light, about 1 micron
- Atomic diameter, $10^{-10}$ meter
- Nuclear diameter, $10^{-15}$ meter
- LIGO sensitivity, $10^{-18}$ meter
Interferometer Detector Concept

https://youtu.be/tQ_telUb3tE
**L**ivingston, Louisiana  
- September 14, 2015 - 09:50:45 UTC: GW150914 is detected by the Livingston instrument, L1.

**H**anford, Washington  
- September 14, 2015 - 09:50:45 UTC: GW150914 is detected by the LIGO Hanford instrument, H1. This coincident detection occurs ~7 ms later than at L1, within the light travel-time between the two sites.

Having interacted briefly with the LIGO test masses, GW150914 propagates onwards essentially undisturbed.

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**LLO Electronic Logbook – September 14, 2015, 09:05 UTC – William Parker:**

**GW150914**

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**SU graduate in the Control Room at LLO during historic discovery¹**

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¹225 Magazine, April 2016, photo by Colin Ritchie.
February 11, 2016
Detection Announcement Day!

LIGO Livingston Observatory

SUBR LIGO Team Members
It truly took a worldwide village!
Statement on the Detection of Gravitational Waves
FEBRUARY 12, 2016 AT 10:32 AM ET BY JOHN P. HOLDREN

Summary:
OSTP Director John Holdren congratulates the team behind the groundbreaking detection of gravitational waves.

“The LIGO effort involved more than 1,000 researchers—some 250 students among them—from 15 countries and a larger number of universities. I join, I’m sure, the entire global scientific community in congratulating them and their funders, foremost among them the National Science Foundation, for their vision, ingenuity, persistence, and collaboration in the successful pursuit of one of history’s greatest scientific discoveries.”

White House Response

White House Congratulates the LIGO Team
Feature Story - February 12, 2016

On Feb 11, 2016, President Obama tweeted his congratulations to the LIGO team:

Einstein was right! Congrats to @NSF and @LIGO on detecting gravitational waves - a huge breakthrough in how we understand the universe.
— President Obama (@POTUS) February 11, 2016

On Feb 12, 2016, John P. Holdren, Assistant to the President for Science and Technology and Director of the White House Office of Science and Technology Policy, posted a statement on the White House blog with congratulations to the LIGO team.

OSTP Dir. Holdren on the groundbreaking detection of gravitational waves. Congrats to @NSF & all behind the effort! → https://t.co/K07WBz5Qxs
— The White House OSTP (@WhiteHouseOSTP) February 12, 2016

Read the full statement on http://www.whitehouse.gov/blog.
GW150914 Signals
VIII. CONCLUSION

The LIGO detectors have observed gravitational waves from the merger of two stellar-mass black holes. The detected waveform matches the predictions of general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.
Reducing Noise in Mirrors via Coating Structure Studies

Surface Morphology and Crystallinity Studies using AFM and XRD Methods

SUBR–LIGO Advanced Optical Materials Laboratory


Opportunities abound for formal and informal science education collaborations and partnerships between the BIG science of LIGO and the local and regional communities!!
Proximity of LIGO site to Southern University
Science Education Program

As a national facility based upon an exciting scientific research mission, LIGO can provide a focus for educational programs in science. A Science Education Program will reach beyond the traditional university role of educating undergraduate and graduate students to reaching K-12 grade level students. The managers of the Caltech, MIT, Hanford and Livingston groups will develop and lead programs in educational outreach to the general public, in on-site educational programs at the Observatory sites, as well as the university campuses, and in supporting program development consistent with other NSF educational initiatives.
LIGO Science Education Center (SEC)

“Using Exhibit-Based Teaching and Learning to Enhance Science Literacy”

Third EDA University Center Conference - Southern University and A&M College
June 17, 2016
LIGO Science Education Center Partnership

“Using Exhibit-Based Teaching and Learning to Enhance Science Literacy”

MISSION

• To develop a Center at the LIGO Livingston Observatory (LLO) equipped with interactive exhibits in LIGO-related science.

• To integrate the LLO Center, its exhibits and activities, into pre-service and in-service education at Southern University Baton Rouge (SUBR).
Exhibit training workshops
Pre- and In-service teacher preparation and docent training
SUBR LIGO Docent Training Program*

Disciplines Represented
- Physics
- Mathematics
- Chemistry
- Biology
- Computer Science
- Education
- Mechanical Engineering
- Electrical Engineering
- Business
- Agriculture
- English

*Southern University at Baton Rouge (SUBR), Annual Collaborative Report (Phase II, Year 5) September 30, 2014, L. Young and J. Meyinsse.

http://www.aapt.org/abstractsearch/fullabstract.cfm?keyID=24069
Local Educational Outreach Partnership

Phase III Funding: $2.5 M for 5 years; NSF PHY-1506269

Goal:
• Strengthen teacher candidate training and clinical faculty professional development focused on inquiry based teaching and learning, using exhibits and “snacks.”

Partners:
• LIGO Livingston Observatory (Livingston, LA)
• SUBR’s Departments of Education, Physics, Mathematics, and Science/Mathematics Education Doctoral (SMED) Program
• San Francisco Exploratorium
• Southern University at New Orleans (SUNO)
• CORE Element (Coordinator of PD in the NOLA area)
• University of Glasgow, Scotland
The detection of gravitational waves from binary black hole mergers has given birth to the new field of gravitational-wave astronomy.

Southern University occupies a unique role in the optical materials research and science education areas within Advanced LIGO.

Significant improvements in our research infrastructure are being realized as a result of our collaboration with LIGO.

Ongoing major enhancements to our science teacher preparation programs are being created and supported by the SUBR-LIGO Local Science Education Partnership.

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Partners, Collaborators and Supporters

LIGO Science Education Center (SEC)

Louisiana State University Center for Advanced Microstructures & Devices
From the Research Lab to Everyday Life
A Quick Look Back:

**Nobel Prizes in Physics**

1956 “.......... discovery of the transistor” W. B. Shockley, J. Bardeen and W. H. Brattain

2000 “for basic work on communication technology” Z. I. Alferon and H. Kramer; Jack Kilby “for his part in the invention of the integrated circuit”

2007 “for the discovery of Giant Magnetoresistance” A Fert and P. Grünberg

2009 “for the invention of an imaging semiconductor circuit - the CCD sensor” W. Boyle and G. E. Smith

1981 “contributions to laser spectroscopy” M. Bloembergen and A. L. Schawlow

**Lastly, let us not forget that the proper function of the GPS system relies upon Einstein’s relativity!**
Meanwhile, stay tuned … this is just the beginning!

Thank You!!

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