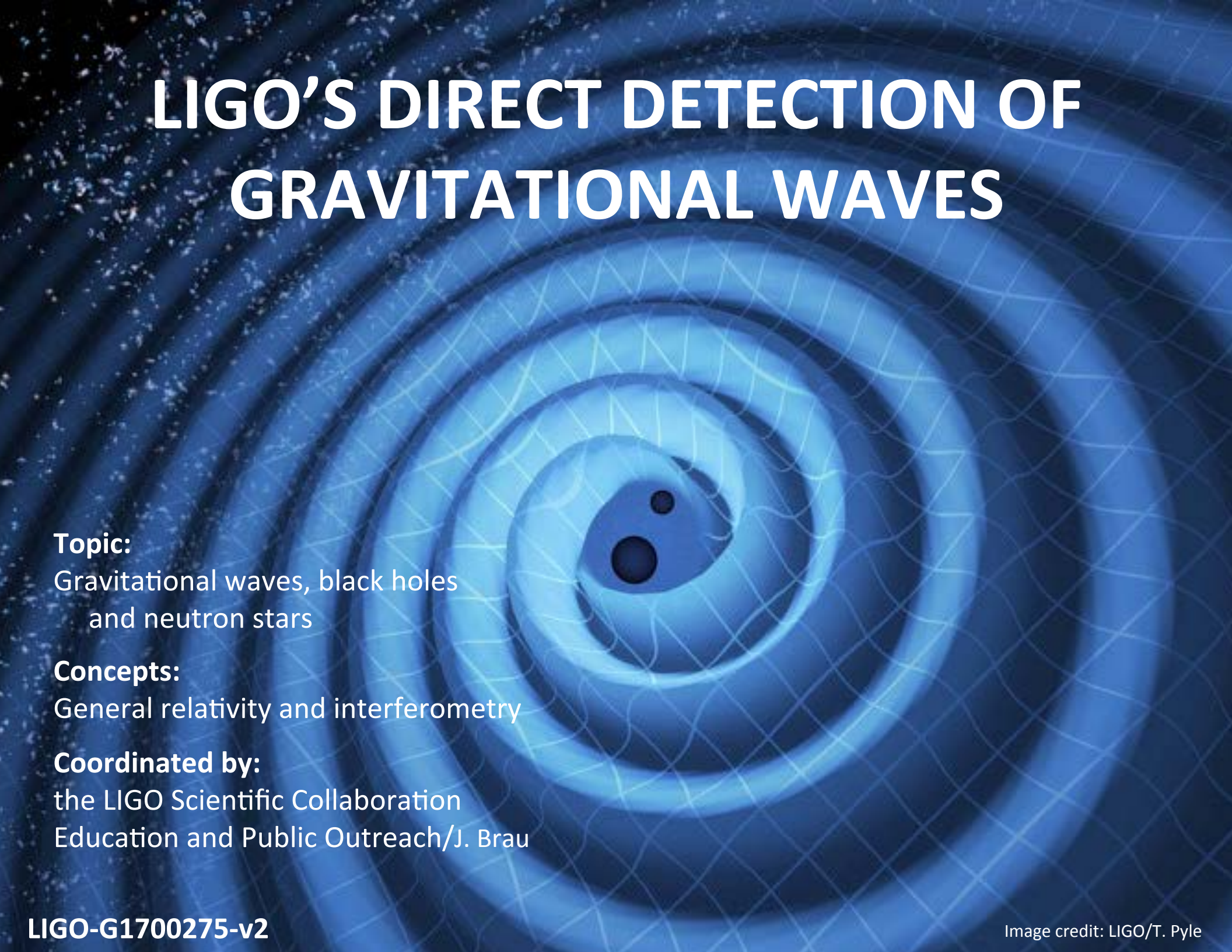
LIGO'S DIRECT DETECTION OF GRAVITATIONAL WAVES



Topic:
Gravitational waves, black holes and neutron stars

Concepts:
General relativity and interferometry

Coordinated by:
the LIGO Scientific Collaboration
Education and Public Outreach/J. Brau

LIGO-G1700275-v2

Image credit: LIGO/T. Pyle

The Discovery

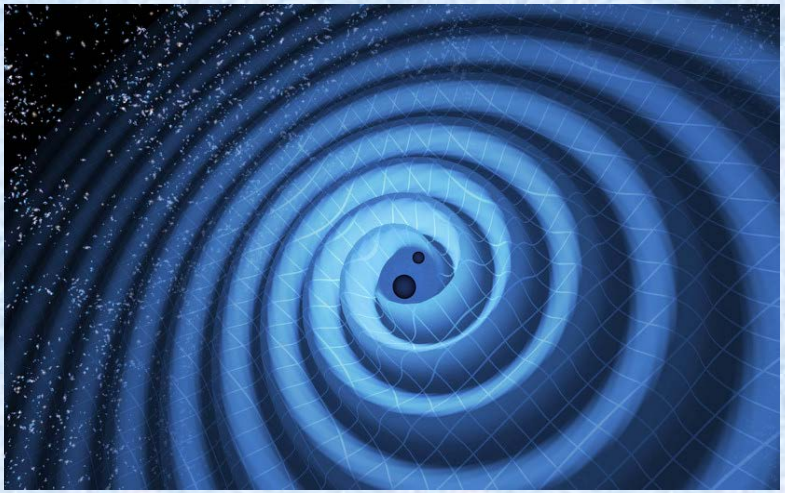
On September 14, 2015, the Laser Interferometer Gravitational-wave Observatory (LIGO) received the first confirmed **gravitational wave** signals.

Einstein's **General Theory of Relativity** predicts that two stars in a binary orbit will generate gravitational waves as the stars orbit each other.

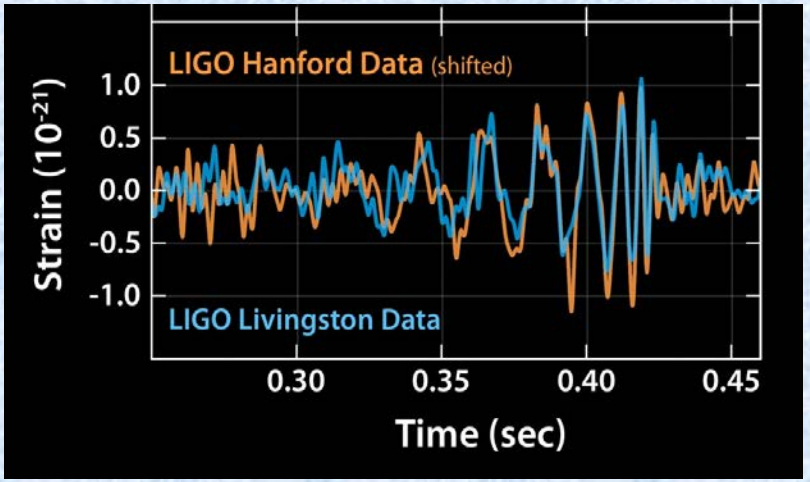
Since that initial discovery, six binary systems have been detected by LIGO and Virgo, and a seventh candidate event is likely real.

Six of the events represent the coalescence of two **black holes** that were previously in mutual orbit, and one came from a **binary neutron star** system.

LIGO's exciting discoveries provide direct evidence of what is arguably the last major unconfirmed prediction of Einstein's General Theory of Relativity.



Merger of two **black holes** creates gravitational waves that ripple outward as black holes spiral toward each other.
Image credit: LIGO/T. Pyle



Ripples were first detected by two LIGO detectors.
Image Credit: Caltech/MIT/LIGO Lab

Discovery Method

Einstein's General Theory of Relativity predicts that two stars in a binary orbit will generate gravitational waves as the stars orbit each other.

Gravitational waves cause spacetime *itself* to stretch in one direction and get squeezed in a perpendicular direction.

The LIGO and Virgo **gravitational wave observatories** are three enormous **laser interferometers** located thousands of kilometers apart.

The change in length of the arms of the **interferometers** is measured as the wave passes.

The LIGO/Virgo **interferometers** are designed to measure the difference in the lengths of the two arms to **1/10,000th the width of a proton!**

Credit: Caltech/MIT/LIGO Lab

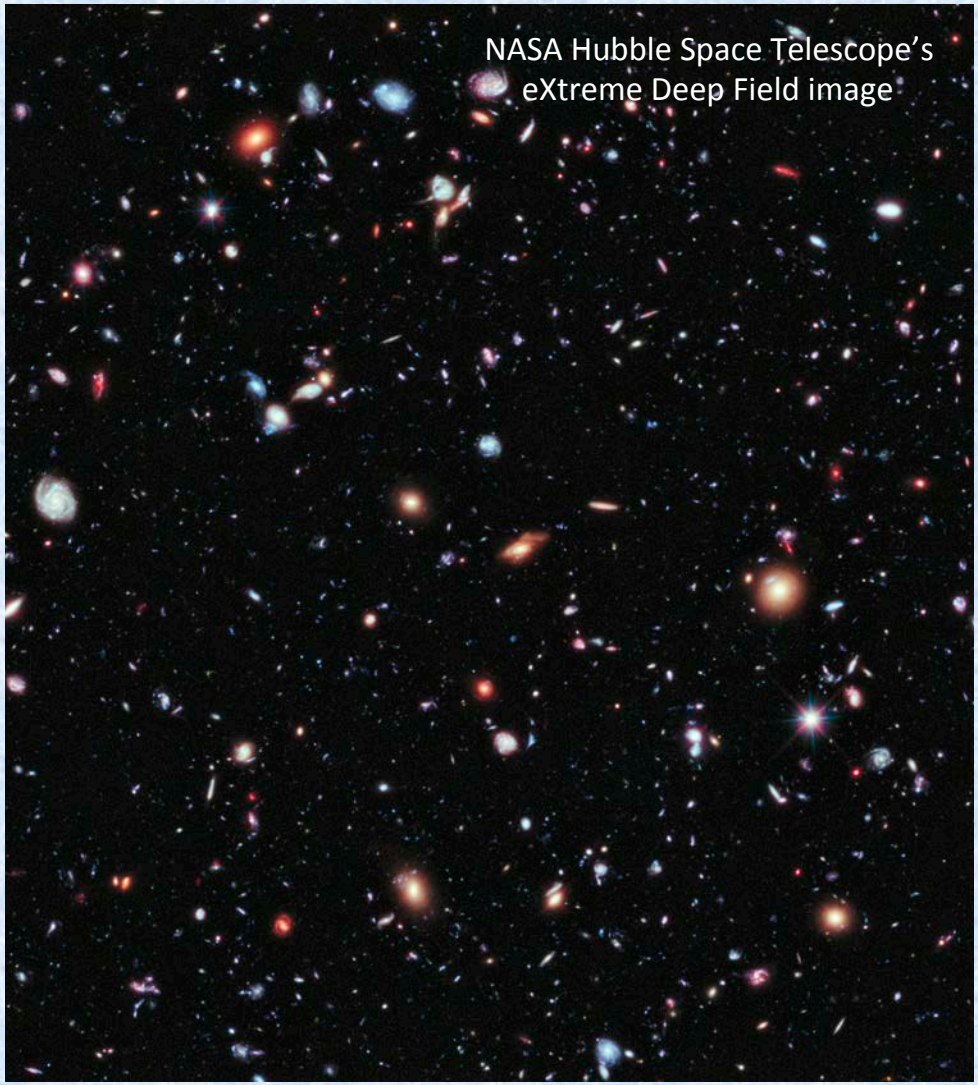
Gravitational Waves Complement Other Observations

Our understanding of the universe is based primarily on observations with electromagnetic radiation (visible light, x-rays, radio waves, microwaves, etc.)

Some types of subatomic particles, including neutrinos and cosmic rays, have also been used to study cosmic objects.

Each provides a **different and complementary view of the universe**.

Gravitational waves offer a completely new window with great potential for discovery of new phenomena, particularly related to merging of massive, compact objects such as **black holes and neutron stars**.



Credit: NASA; ESA; G. Illingworth, D. Magee, and P. Oesch, UC, Santa Cruz; R. Bouwens, Leiden University; and the HUDF09 Team

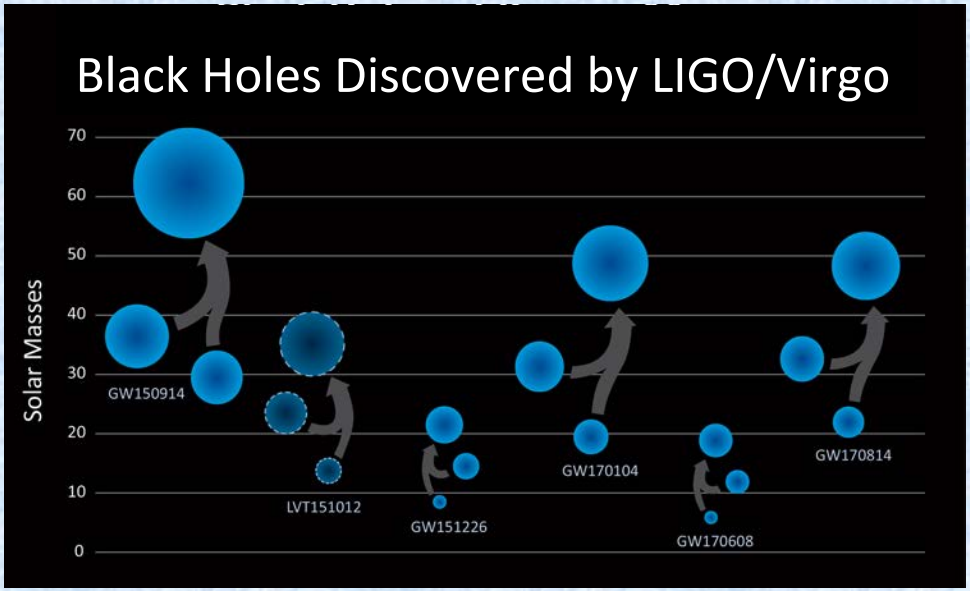
Advances from These Discoveries

LIGO/Virgo has significantly increased the number of **black holes** with known masses over those previously known from X-ray studies.

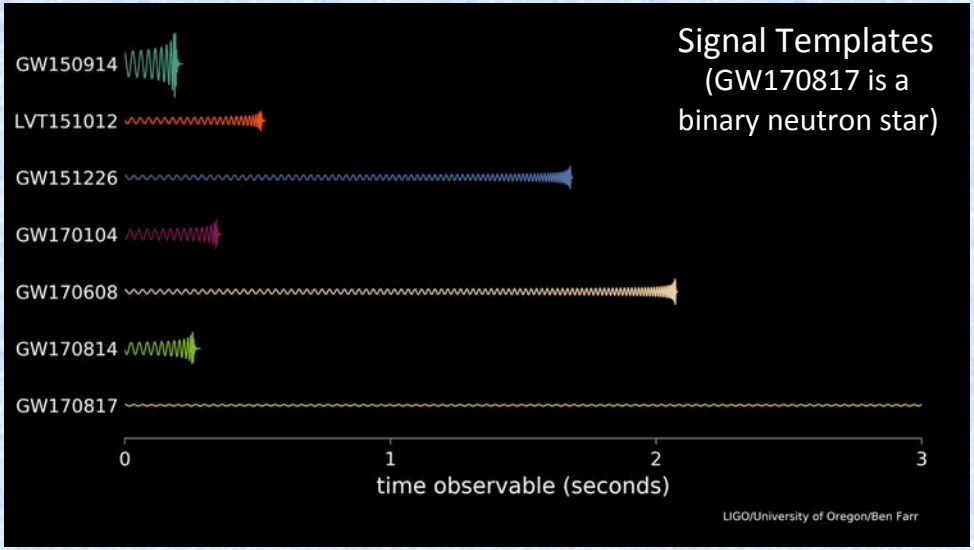
The observatories have now detected five binary **black hole** mergers, as well as a sixth candidate event (shown with dashed border) that was too weak to be conclusively claimed as a detection.

LIGO determined the individual masses of the **black holes** before they merged, as well as the mass of the **black hole** produced by the merger.

Improvements in **gravitational wave** discovery potential are underway with upgrades to LIGO/Virgo and extension of the global detector network to include KAGRA in Japan, and a possible third LIGO detector in India.



Credit: LIGO/Caltech/Sonoma State (Aurore Simonnet)



Credit: LIGO/University of Oregon/Ben Farr

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Resources

LIGO Scientific Collaboration (LSC) homepage: http://www.ligo.org

includes links to two discovery publications, *PRL* 116, 061102 (2016)) and *PRL* 116, 241103 (2016)

Additional information about detections made by LIGO to date: http://ligo.org/detections/

The LSC is a collaboration of more than 1200 scientists from over 100 universities and research institutions in 18 countries.

GEO600 homepage: http://www.geo600.org

Advanced Virgo homepage: http://public.virgo-gw.eu/language/en/

The Virgo Collaboration has more than 300 members from many institutions in six European countries.

LIGO Open Science Center (with access to LIGO data):

https://losc.ligo.org/about/

Educator's Guide

https://dcc.ligo.org/LIGO-P1600015/public