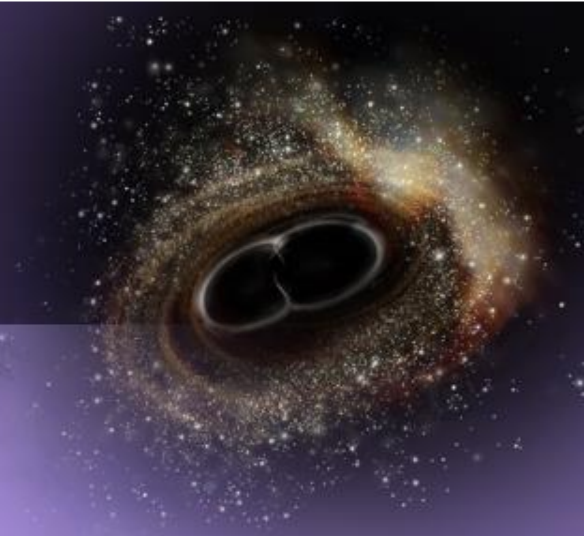

Exploring Gravitational Waves in the Classroom

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Sonoma State University
Education and Public Outreach

Outline

- Big Ideas in Cosmology
  - Special Relativity (ch 9)
  - General Relativity (ch 10)
- LIGO Educator Guide for GW150914
  - Background information
  - Classroom demonstrations
- Online courses for LD college and AP HS instructors
  - LIGO: Waves and Gravity (Summer 2015)
  - LIGO: Detecting Gravitational Waves (in progress)
- Contemporary Physics Education Project

Special Relativity (ch 9)

- 9.1 Principles of Special Relativity
- 9.2 Time Dilation
- 9.3 Length Contraction
- 9.4 Geometry of Special Relativity: Spacetime
- 9.5 Applications of Spacetime (Moore)
- 9.6 Mass and Energy
- 9.7 Faster Than Light?
- Wrapping it Up: A Trip to Alpha Centauri

General Relativity (ch 10)

- 10.1 Einstein's Equivalence Principle
- 10.2 Gravity and Curvature
- 10.3 What is Curvature?
- 10.4 Tests of General Relativity
  - 10.4.1 The Orbit of Mercury
  - 10.4.2 Light Bends Around the Sun
  - 10.4.3 Gravitational Redshift
  - 10.4.4 Dragging of Reference Frames by Moving Objects
  - 10.4.5 Gravitational Radiation (UPDATED FOR GW150914)
- 10.5 The Source of Gravity
- Wrapping it Up: Curved Spacetime Around a Star

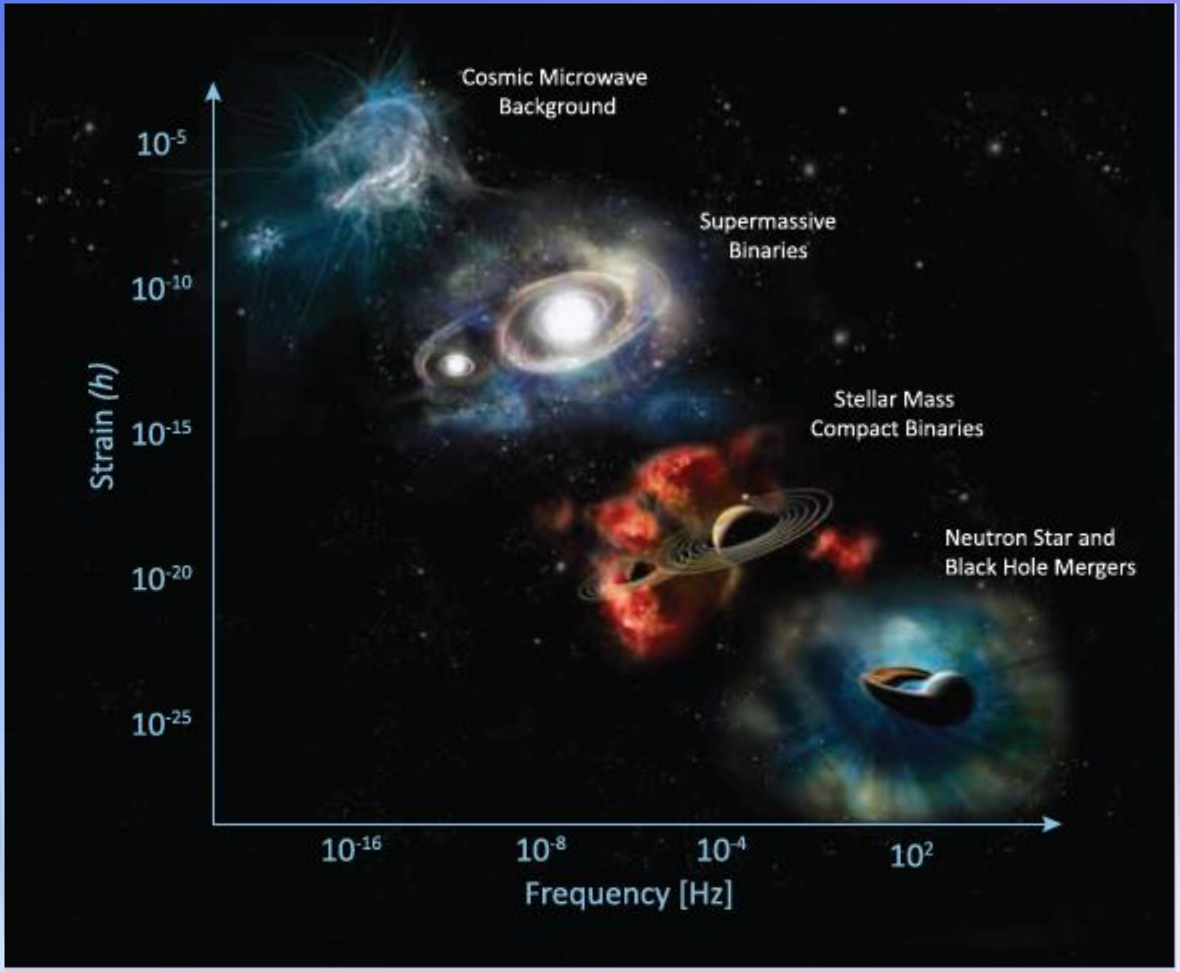
LIGO GW150914 Educator Guide

- Quick project commissioned by NSF to accompany press packet for DC press conference on 2/11/16
- Adapted background material from "Big Ideas" chapter on General Relativity
- Adapted classroom activities that have been used for pulsars and black holes for Fermi and other NASA missions

Background Material

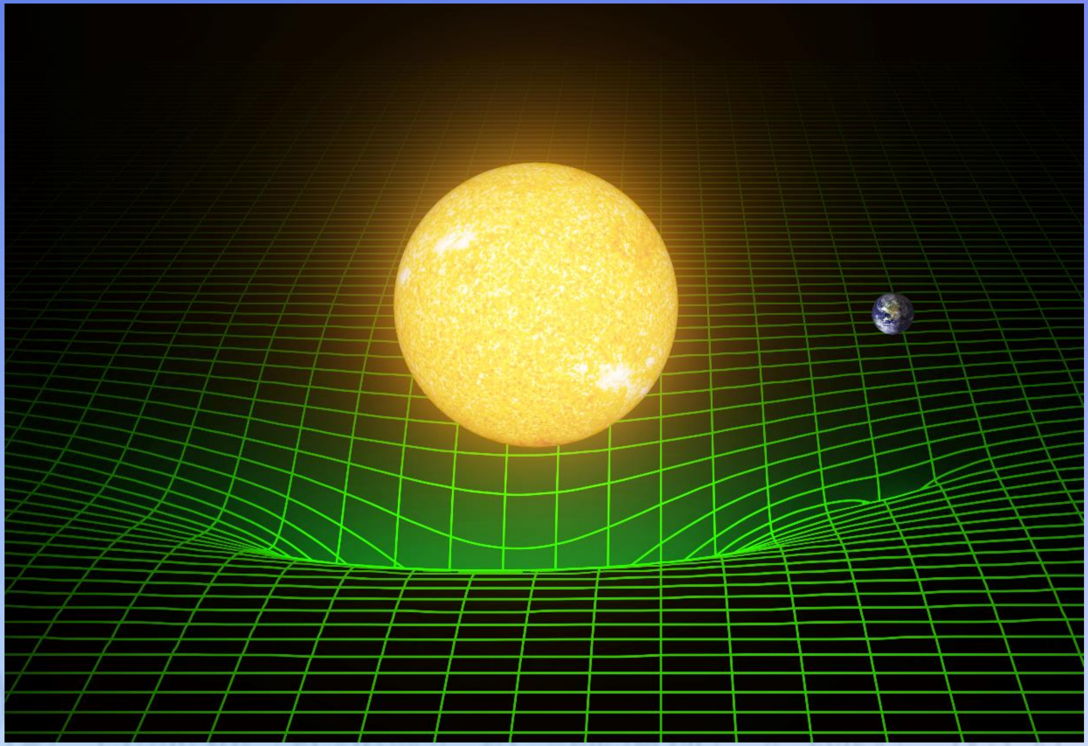
- Gravitational Waves as Signals from the Universe
- Gravity from Newton to Einstein
- Gravitational Waves
- The Direct Observation of Gravitational Waves by LIGO
- Black Holes

New visualizations

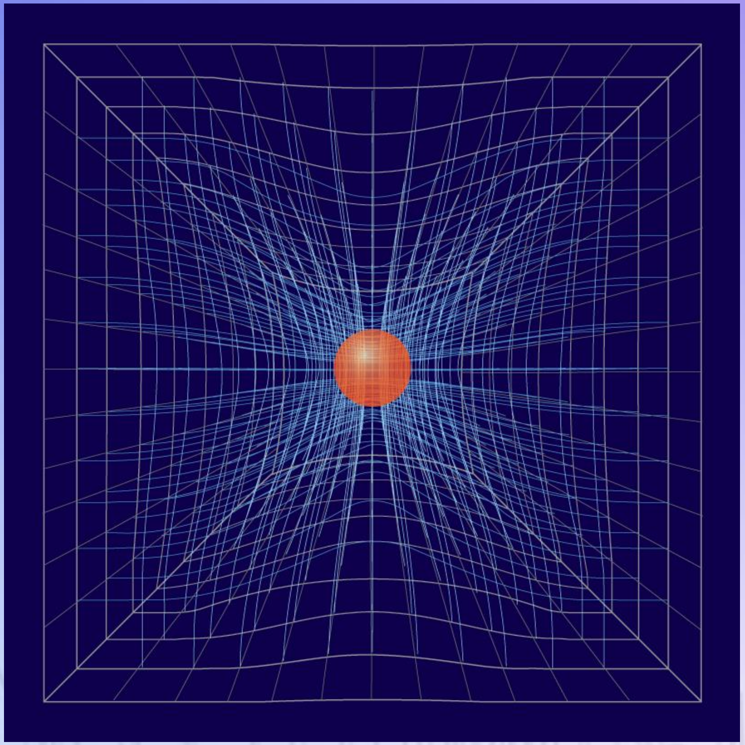


Credit:SSU/A. Simonnet

Addressing misconceptions



Credit:LIGO/T. Pyle



Credit:SSU/A. Simonnet

Classroom Activities

Activity 1 – Coalescing Black Holes

Brief overview:

Students interact with a demonstration of orbiting spheres that have an increasing orbital frequency as they coalesce.

Science Concepts:

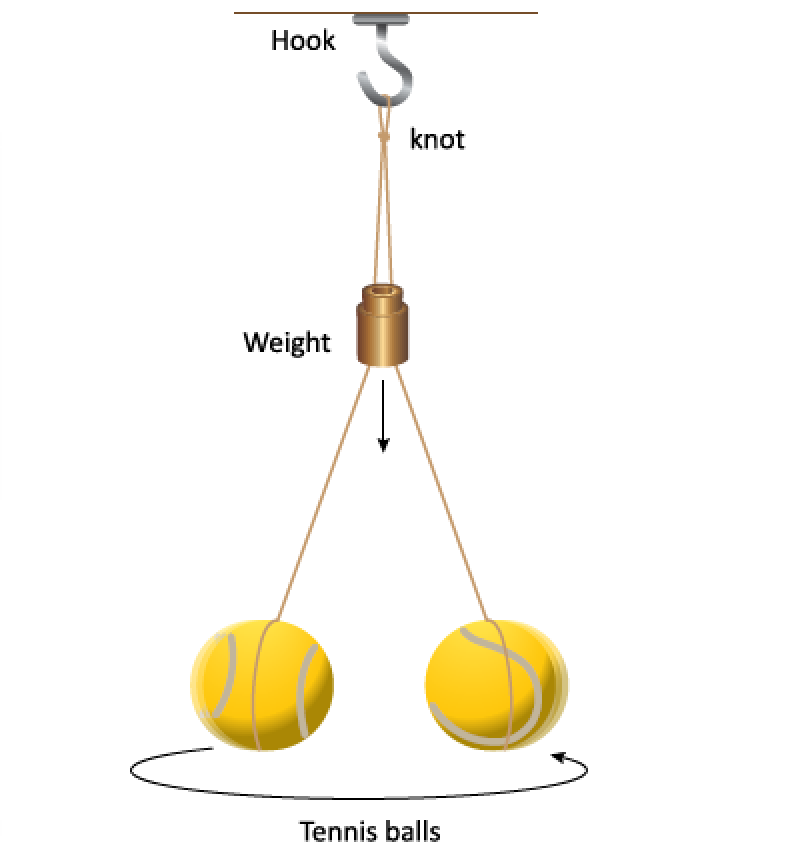
Gravitational waves are ripples in spacetime produced by some of the most violent events in the cosmos, such as the collisions and mergers of massive compact stars or black holes. These ripples travel at the speed of light through the Universe, carrying with them information about their origins.

Duration: 30 min

Essential Question:

What happens when two black holes spiral in towards each other?

Grades: 5 – 12



Classroom Activities

Activity 2 – Warping of Spacetime

Brief overview:

Students explore the behavior of two orbiting spheres in spacetime.

Science Concepts:

A pair of orbiting black holes will produce gravitational waves, which are ripples in the fabric of spacetime. Gravitational waves will carry energy away from the pair, causing their orbit distance to shrink and their orbital period to decrease. Eventually the black holes will coalesce. LIGO's detectors can measure the gravitational waves produced by the system during the coalescence.

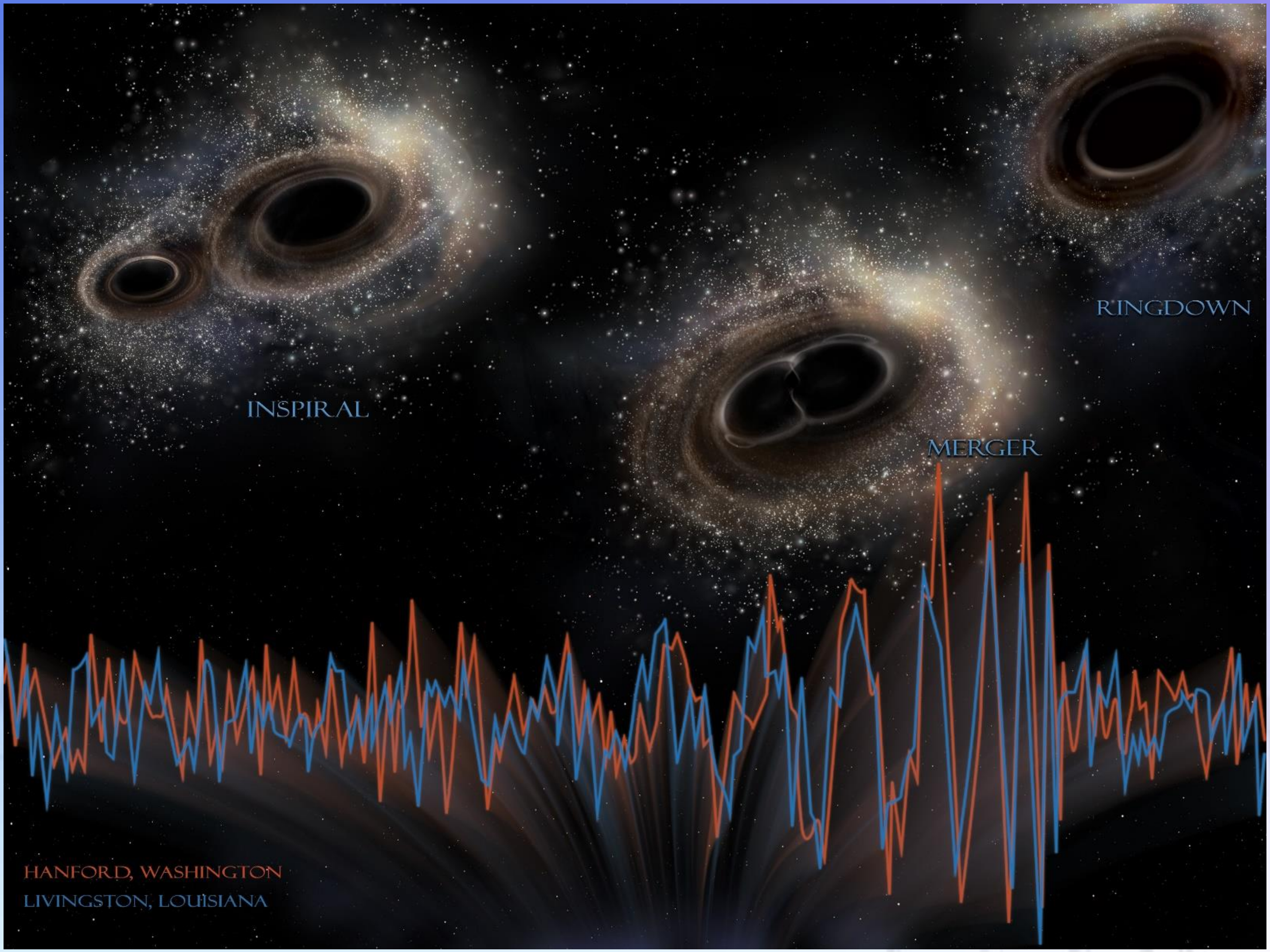
Duration: 30 min

Essential Question:

How do binary black holes warp spacetime?

Grades: 5 – 12

APOD 2/11/16


INSPIRAL
MERGER
RINGDOWN
HANFORD, WASHINGTON
LIVINGSTON, LOUISIANA

LIGO: Waves and Gravity

- Offered for academic or continuing education credit during July-August 2015
- Online course – 11 enrolled (7 for CEUs, 4 for academic credit)
- Pre- and post-surveys done by WestEd
  - Only 4 people filled out the post-survey
- We surveyed the teachers background and how they taught E&M and Special Relativity before taking our class

Course participants

- 2 AP high school and 8 community college
- 7 with MS degrees, 3 with PhDs
- Teaching for 5 – 27 years, most at higher end
- 9/10 also teach astronomy
- 8 teach integral form of Maxwell's Eqns
- 9 do NOT teach differential form
- All 10 teach Special Relativity
- 4/10 were at least exposed to GR in the past
- 9/10 do not teach or mention GR in class

Course content

- Seven units of material
  - Light (chapter 2 from Big Ideas)
  - Learning More about Light (new, following B&B)
  - Classical Physics: Gravity and Energy (ch. 7)
  - Special Relativity (ch. 9, following Moore)
  - General Relativity (ch. 10)
  - Geometry and Gravity for Weak Fields (new)
  - Astrophysical Sources of Gravitational Waves (new)
- Plus Resources (lots of links)
- All the newly created material is available online through: http://epo.sonoma.edu/ligo

Learning More About Light

- Reintroduced them to div/grad/curl form of Maxwell's Equations
- Demonstrated that accelerating charges produce electromagnetic waves in a dipole configuration following Bekefi & Barrett (MIT 8.03 textbook)
- Provided vector operator math review of div/grad/curl operators

Geometry and Gravity of Weak Fields

- Extends Special Relativity concepts into accelerating frames, connecting to Maxwell's Equations.
- A more mathematical treatment of curvature leads up to the Einstein Field Equations.
- Applications of the Field Equations to weak fields and predictions for gravitational waves
- Includes extensive tensor math supplement
- This was very hard for them to do – only 3 students tried to do the homework for this section (one of whom had GR as a graduate course).

Astrophysics of GW sources

- This section was easier and not so mathematical
- Summarizes the physics and expected signals from likely sources of gravitational waves:
  - coalescing binary systems
  - impulsive events (such as supernovae or gamma-ray bursts)
  - continuous wave sources (such as spherically asymmetric pulsars).
  - stochastic sources (briefly)
- Other observatories for different bands in the gravitational wave spectrum

Final Reflection

- Essay on how they would be likely to use the course materials in their lower-division college physics classroom
  - “a renewed awareness for what my students must go through when they are tackling new and/or difficult topics”
  - “given me some new ideas about using technology to a greater degree in my courses”
  - “as much as I love discussing entropy or the conservation of angular momentum, people are more likely to ask about black holes, gravitational waves, etc.”
  - “We will likely make use of some of the sounds and animations of mergers provided from this course”
  - “Currently, there is a short section on gravity as a field, and this is optional. There aren’t any activities to introduce the concepts and simple calculations about fields in general, as applied specifically to gravity.”

Final Evaluation

- The amount of time participants spent on each section and on looking at resources varied greatly, ranging from 1-8 hours per section.
- All participants would "definitely" sign up for the course again
- *"FYI, your documents are the first docs I have ever read that made this material understandable. I have tried several texts, and they are SO mathematical early on that I could never see the physics behind the mathematical thicket."*

LIGO: Detecting Gravitational Waves

- Course is now in preparation – begins June 21
- GW150914
- Understanding the LIGO interferometer
  - Michelson interferometer review
  - Actual LIGO hardware
  - Peter Saulson's heuristic explanation
  - Noise and Noise Mitigation
    - Seismic Noise (I2U2 lab)
    - Thermal Noise
    - Quantum Noise / Laser Instability

LIGO: Detecting Gravitational Waves (continued)

- Signal Extraction
  - Simulating the astrophysical sources
  - Simulating the LIGO signals
  - Matching templates to signals
  - Correlated excess noise
- Upgrades for the future
  - Squeezed light (Mavalvala and Evans)

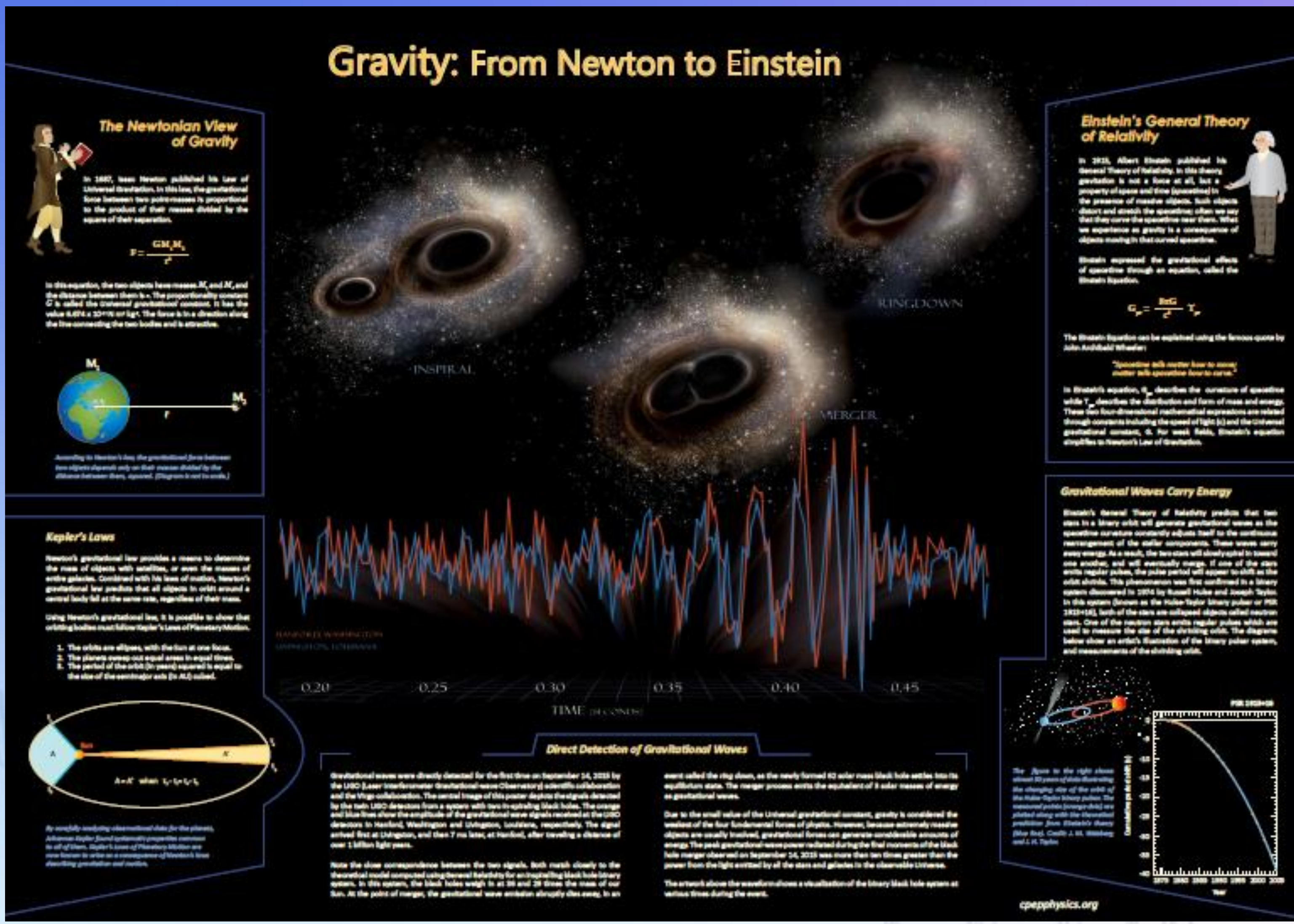
LIGO Open Science Center

- https://losc.ligo.org
- Currently offers access to data prior to "Advanced LIGO" – S5 and S6 data sets
- PLUS DATA AROUND GW150914
- Uses python and specialized viewing tools
- Tutorials included! (S5 data)
- Examples of student and citizen scientist projects: https://losc.ligo.org/projects/

Contemporary Physics Education Project (CPEP)

- Non-profit group that created the famous particle physics poster (and more!)
- New section on Gravitation – please join!
- Creating a new poster and online materials for classrooms
- We would appreciate feedback on the new poster before we print it for sale through their website http://CPEPphysics.org

Poster draft



Summary

- We have created a variety of materials that might be useful to your GE and majors classes
- Big Ideas in Cosmology http://greatriverlearning.com/Cosmology

Or contact Kim Coble or me for examination

- All NSF-funded materials available through http://epo.sonoma.edu/ligo
- New CPEP materials will eventually be at: http://cpepphysics.org/gravitation.html