Davidson Scholars Lecture

Einstein, Black Holes and Gravity Waves, oh my!

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Outline

• Quick overview of what happened
• Backtrack and learn some of the physics, especially General Relativity
  - Gravity, Black holes and Gravity waves
• Back to the discovery of Gravity Waves
• Why it’s important in many ways, and why it’s not that new in others
About a billion years ago (billion light-years away), two $30M_{\text{Sun}}$ black holes spiraled in together to create a $\sim55M_{\text{Sun}}$ black hole. This merger was so violent that it emitted a huge amount of energy in gravity waves (about 5 solar masses) over a short amount of time that were recently discovered here on Earth by the LIGO experiment.

Note: This is NOT the discovery of the century (IMHO), it is the discovery that took a century.

- Although it IS pretty awesome.
Einstein in the 1910's

• In the early 1910's Einstein was thinking about some recent experimental results that didn't make any sense to him using Newton's theories

• Decided we need new ways of thinking about space, time and Gravity

• Einstein says that Newton's Laws aren't really quite right...

• Einstein’s theory is known as the “General Theory of Relativity”
Newton vs. Einstein

Newton: The Earth moves around the Sun because of “the force of gravity” is pulling it.

Einstein: There is no “force” of Gravity, the Earth moves in a “straight line” around the Sun in the curved space-time created by the Sun.

This is a VERY different way of thinking about things...
Curved Space?

An analogy is to think of curved space-time as looking like one of those gravity wells you’ve probably seen.

1st floor of the Mitchell Physics building (MPHY)
Another Weird Thing: Mass Curves Space-Time

Think of each of the heavy things in the universe (stars, planets etc.) like a ball in the middle of a taut rubber sheet that represents space-time.

The weight of the ball will make it sink into the rubber sheet, creating a cone shaped dent around it.
Mass Curves Space

The heavier the ball, the bigger the dent in space-time!
A mass moves in a “straight line” in curved space-time

In this example, this straight line in curved space-time makes the path of the small ball look like something is pushing it toward the big ball in 3-dimensions.
**Newton:** The Earth moves around the Sun because of "the force of gravity" is pulling it.

**Einstein:** There is no force, the Earth moves in a straight line in four dimensions, but the curved space around the Sun makes it go in an orbit in the three space dimensions.
The way the Planets go Around the Sun in General Relativity
From Curved Space Time to Gravity Waves

- If I have a star, or black hole, just sitting in space then other things know where it is because of the curvature of space-time.
- If it's just sitting there (or moving with a constant velocity) space-time isn’t changing.
- If it **accelerates**, then this information is passed through space-time at the speed of light as gravity waves.
  - Similar to if an electric charge was accelerated, or if I dropped a rock in water (or dragged my finger through it).
First Indirect Evidence of Gravity Waves

- In 1974, Taylor and Hulse discovered two neutron stars (one of which was a Pulsar which is VERY bright) orbiting each other
- They measured the period (how fast they orbit) and saw that they were CLEARLY slowing down
- *Why were they losing energy?* They were emitting gravity waves exactly as predicted by General Relativity
  - Nobel Prize 1993
  - Been looking for DIRECT detection ever since

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Nobel Prize 1993
Two Black Holes Colliding/
Gravity Waves

From the Warp of Space-
Time Point of view

https://www.youtube.com/watch?v=qfdygftype0TL2U
Gravity Waves Moving Through Space

A good set of short clips that help tell the story, including how the gravity waves got to us and how they were detected

https://www.youtube.com/watch?v=FlDtXIBrAYE
Catching a wave

As Einstein calculated, a whirling black hole-shaped mass, such as two black holes spiraling together, radiates ripples in space-time: gravitational waves.

Zipping along at light speed, a wave stretches space in one direction and squeezes in the perpendicular direction, then reverses the distortions.

LIGO has detected waves of wavelength roughly equal to the distance between the detectors. The waves stretch each detector by about 1/10,000 the width of a proton.

Light bounces back and forth in the 4-kilometer arms of a LIGO interferometer. When a wave makes the arms unequal in length, light leaks out the interferometer’s “dark port,” revealing the wave.
What the Data Looked Like

Ripples In Space-Time that reached us from two $\sim 30M_{\text{Sun}}$ Black Holes as they spiral into each other about a billion light-years away.
Conclusion

• The first direct observation of gravity waves is very exciting, and many years in the making

• This allows us to see things we’ve never seen before that don’t produce light

• Lots of fun questions still remain to be answered
  - How often does this happen in the universe?
  - Where did 30 solar mass black holes COME FROM?
  - What other new and exciting things will come from this powerful new technology?

• Enjoy!
Interested in learning more?

- Physics department offers a course entitled "Big Bang & Black Holes"
  (ASTR/PHYS 109)
  - Covers Stephen Hawking’s "Brief History of Time"
  - Origin and Evolution of the Universe
  - How do stars form?
  - What is Dark Matter? Dark Energy?
  - What are Black Holes?
  - More on General Relativity, Quantum Mechanics and Particle Physics
  - Has a lab (if you want)
  - There is an option to take is an Honors class

http://people.physics.tamu.edu/toback/109/

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