

A visualization of gravitational waves, showing concentric, distorted rings of light in shades of blue, purple, and white, set against a dark background. The waves appear to be emanating from a central point, creating a ripple effect.

Gravitational Wave Detection and the AU Optics Olympiad

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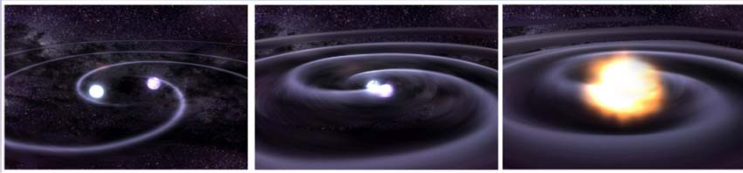
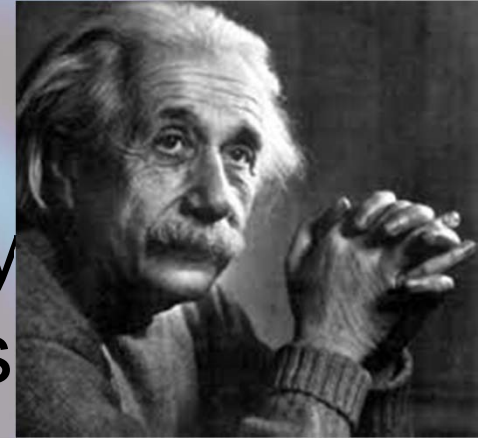
July 14, 2015



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Gravitational Waves

- Gravitational waves are a prediction of Einstein's theory of gravity
- Similar to light waves from electricity and magnetism (Maxwell) equations



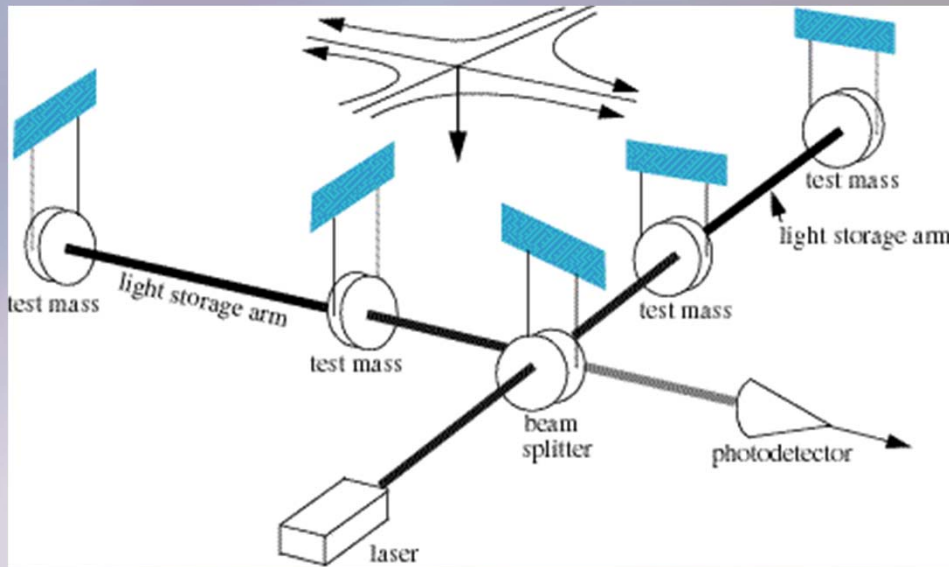
- Two major differences
- Spin two (tensor) shape
- Much smaller amplitude



- Strain $\frac{\Delta L}{L} \cong 10^{-22}$

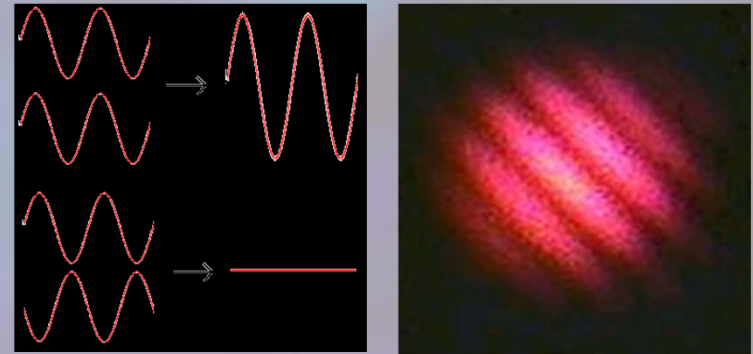
- Kilometer baseline, subnuclear length changes

Interferometry



- Light goes down two perpendicular arms
 - Similar to Michelson-Morley
- Mirrors are free to move
 - Suspended as pendulums
 - Isolated from seismic noise

- Returning light recombines
 - Constructively: equal arm length
 - Destructively: different arm lengths
- Gravitational wave
 - Stretch one arm, shrink other



Interference of Light



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LIGO Detectors

- **L**aser **I**nterferometer **G**ravitational-wave **O**bservatory (**LIGO**)
- Two sites in the United States
 - Livingston, Louisiana (LLO) and Hanford, Washington (LHO)
- Sites chosen for low seismic noise



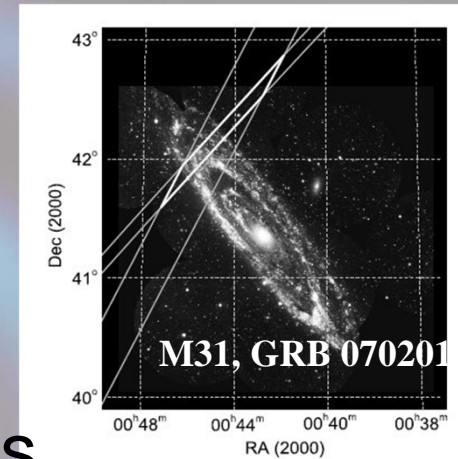
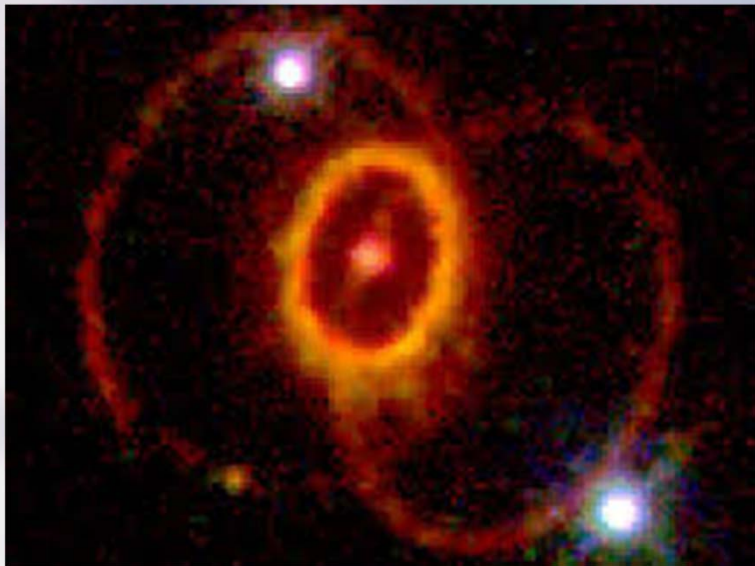
- 4 kilometer-long beam tubes
- Entire beam path in vacuum





LIGO Astrophysics: Burst and Inspiral Sources

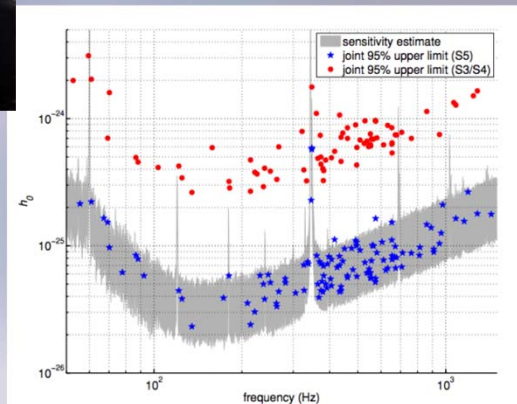
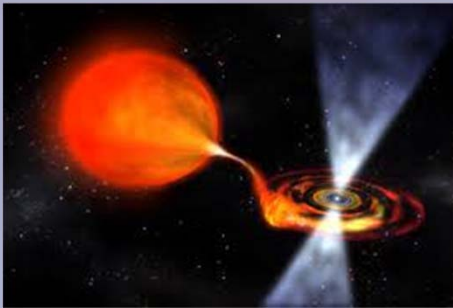
- Inspirals are two neutron stars or black holes orbiting around each other
- Gamma ray bursts (GRBs) may be compact body inspirals
- Showed that GRBs in two nearby galaxies were **NOT** inspirals



- Bursts are other short GW signal
 - Some supernova
 - Rapid changes to neutron star structure
 - Other “bumps in the night”



LIGO Astrophysics: Pulsars and Stochastic



- Pulsars are rotating neutron stars
- Non-spherical pulsars give off GW
- Upper limit on bumps

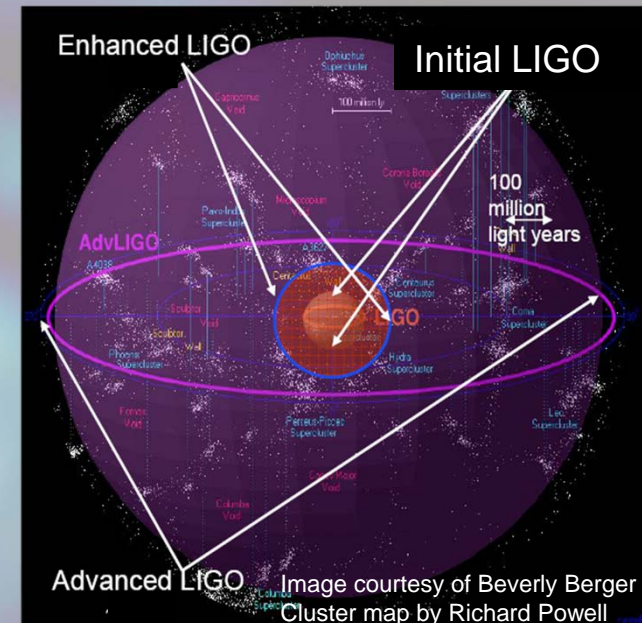
- Gravitational wave background from Big Bang
- Upper limit on strength
- May be too small even with best LIGO sensitivity



'Listen! There they are again - echoes of the Big Bang. The beginning of creation!'

SOURCE: BICEP2

- Goal: 10 X sensitivity
 - 1000 X rate
 - 10 – 5000 Hz, wider bandwidth
 - 200 Mpc NS inspiral range
 - Inspirals possible ~ 1/month
 - One day with Advanced LIGO = a few years with initial LIGO



- Construction project complete

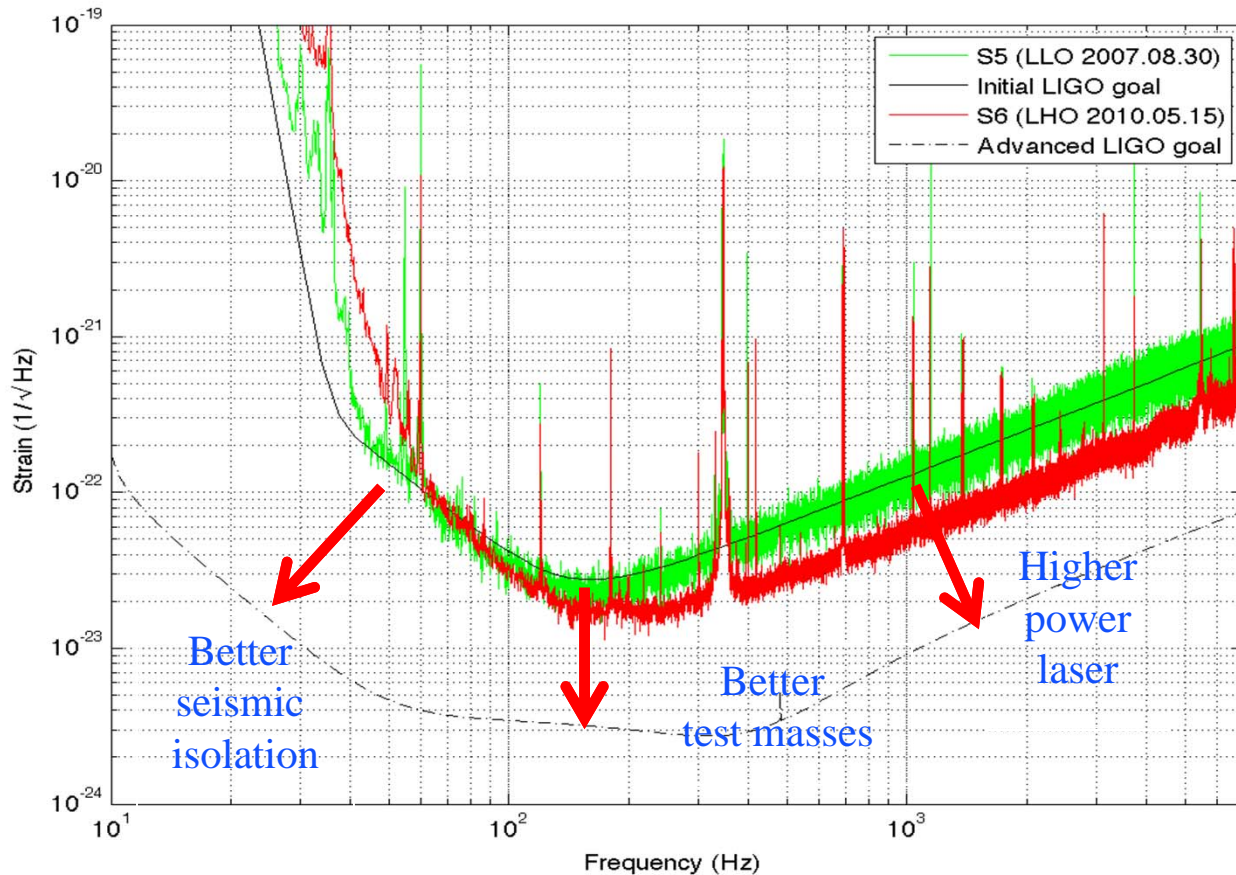
- Installation started 2010
- Installation finished Feb 2015
- Collecting first data fall 2015
- Goal: first detection by Einstein centenary





Advanced LIGO Sensitivity

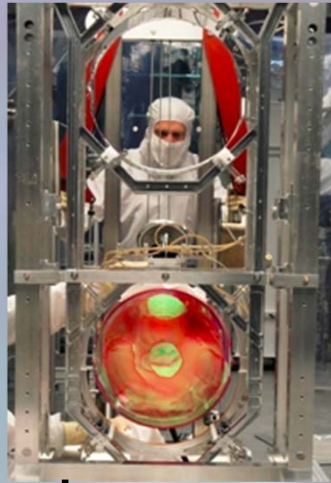
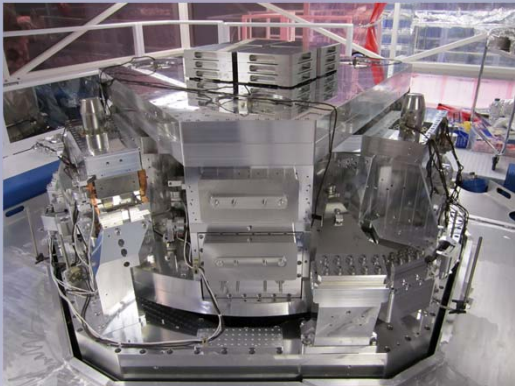
Limited by Earth's motion, thermodynamics, and quantum mechanics





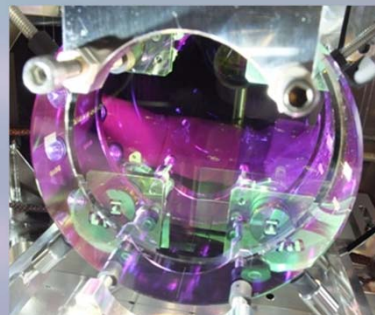
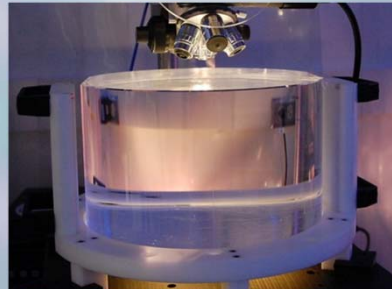
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Advanced LIGO Hardware



- Seismic isolation
 - Hydraulics and two stage, mass/spring system
- Quadruple suspension
 - Final stage silica fibers to reduce thermal noise

- 40 kg silica optics
- Optical coatings
 - Specially developed material for low noise
- Laser
 - Nd:YAG 1064 nm
 - 180 Watts
 - Reduces shot noise





LIGO

LIGO at AU



- AU is a member of the LIGO collaboration
 - 80+ institutions, 16 countries
- International collaboration
 - 900+ total members, 500+ US



LSC

LIGO
Scientific
Collaboration



AU LIGO Lab Summer 2013

- Campus lab working on reducing thermal noise
 - Improve mirror properties
- Next generation detectors
- Train students to enter field

The LIGO logo consists of the word "LIGO" in a bold, black, sans-serif font. To the left of the text are several concentric, curved lines that resemble the ripples from a gravitational wave detector.

Secondary School Teachers

- LIGO Livingston Observatory in Louisiana partners with regional organizations to provide teacher training
www.ligo-la.caltech.edu/SEC.html
- LIGO Hanford Observatory in Washington state offers stand alone summer workshops for teachers
www.ligo-wa.caltech.edu/prof_dev.html
- LIGO participates in remote workshops for teachers by invitation from organizers
- Hanford observatory also provides summer teacher internships through the STAR teacher program
www.ligo-wa.caltech.edu/internships.html
- Contact William Katzman (wkatzman@ligo-la.caltech.edu) and Dale Ingram (ingram_d@ligo-wa.caltech.edu)





LIGO

LIGO Online

- On the web

www.ligo.caltech.edu

www.ligo.org

- On Facebook

www.facebook.com/LigoScientificCollaboration

- On Twitter

twitter.com/LIGO

- On Youtube

LIGO Generations www.youtube.com/watch?v=3xVUmmSFxXu

LIGO, A Passion for Understanding

[www.youtube.com/watch?v= OPTo1kPJI](http://www.youtube.com/watch?v=OPTo1kPJI)

- LIGO Magazine

www.ligo.org/magazine.php

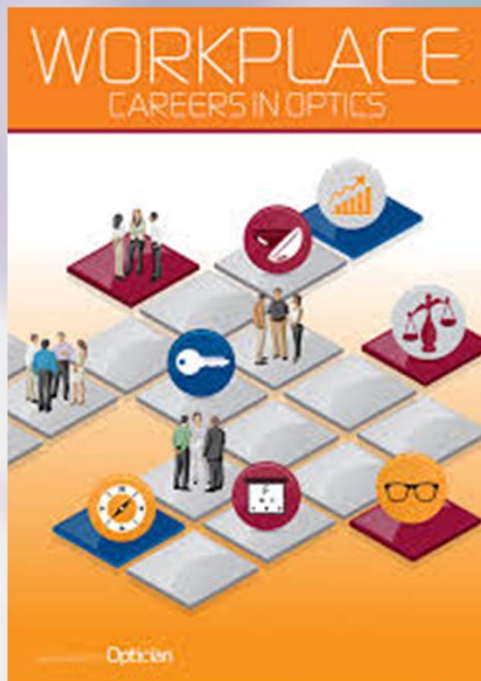




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AU Optics Olympiad

- LIGO group at American University starting an Optics Olympiad for DC high school students
- Day of individual and group competition in optics, physics, and science



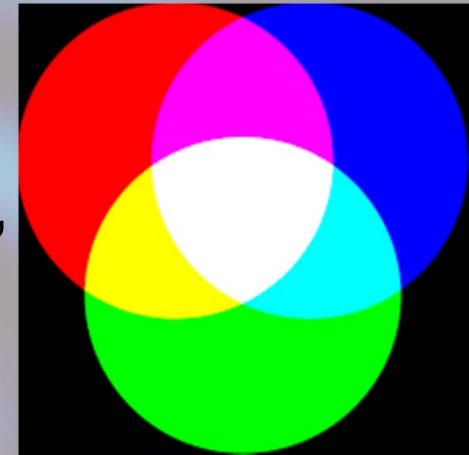
- Give overview of optical science
- Discuss wide application of optics
- Tips on applying to college
- Introduce STEM careers
- Build collaboration between research scientists and schools



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Optics Olympiad Schedule

- Morning - optics demonstrations
 - Interferometry, color and light mixing, Snell's law and trigonometry, telescopes, total internal reflection, lasers, IR light
 - Individual quizzes with trophies

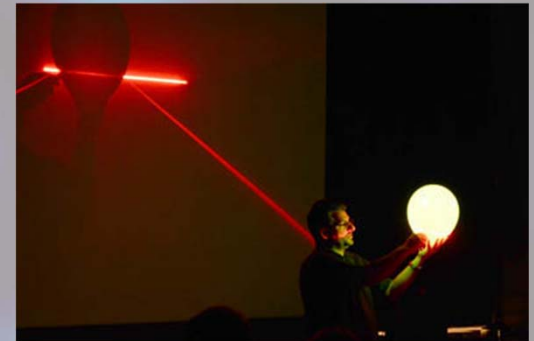


- Lunch - guest speaker, panel discussions, and lab tours
 - MIT Prof. about quantum optics
- Afternoon – team competition based on optics trivia questions
 - Double elimination tournament
- Prizes awarded at end of day



Participate in the Optics Olympiad

- Organizing now, looking for help
- Advisory committee members
Speakers, demonstrations, class recruitment, “day of” volunteers, etc.
- Participate in Optics Olympiad
- Tentative date Friday March 4, 2016
- Sign up sheets at front



- Need feedback on ...
 - What grade level to target?
 - Appropriate level of math (and physics)
 - How to recruit schools
 - Logistics for schools
 - Other issues we aren't anticipating



Example Demonstration Interferometer



- Learning Objectives
 - Understand that light is a wave
 - Be able to describe how interference of waves occurs
 - Know the length scale of the wavelength of visible light

- Script

- Generate interest by showing sensitivity
- Explain interference of light acting as a wave
- Show practical application by measuring < 1 micron of movement

