Gravitational Waves
A New Kind of Astronomy

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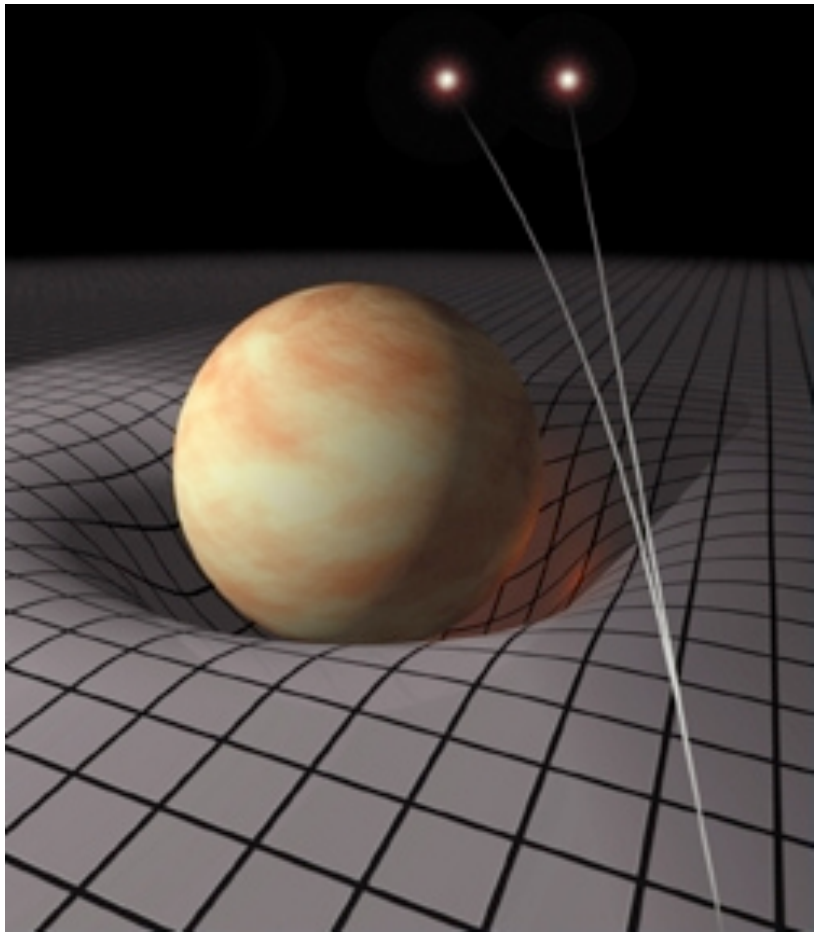
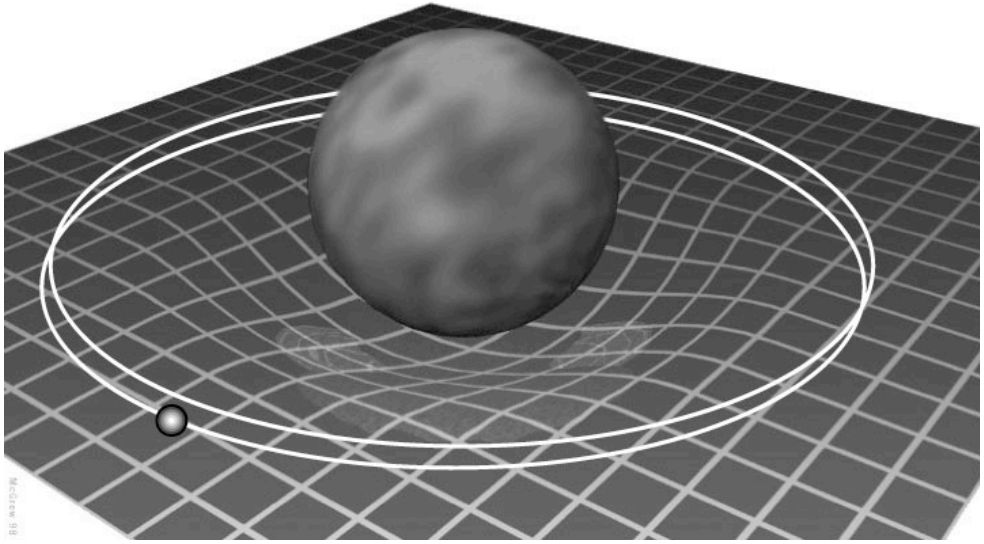
Andrews University

Background picture from http://cgwp.gravity.psu.edu

What is a Gravitational Wave?



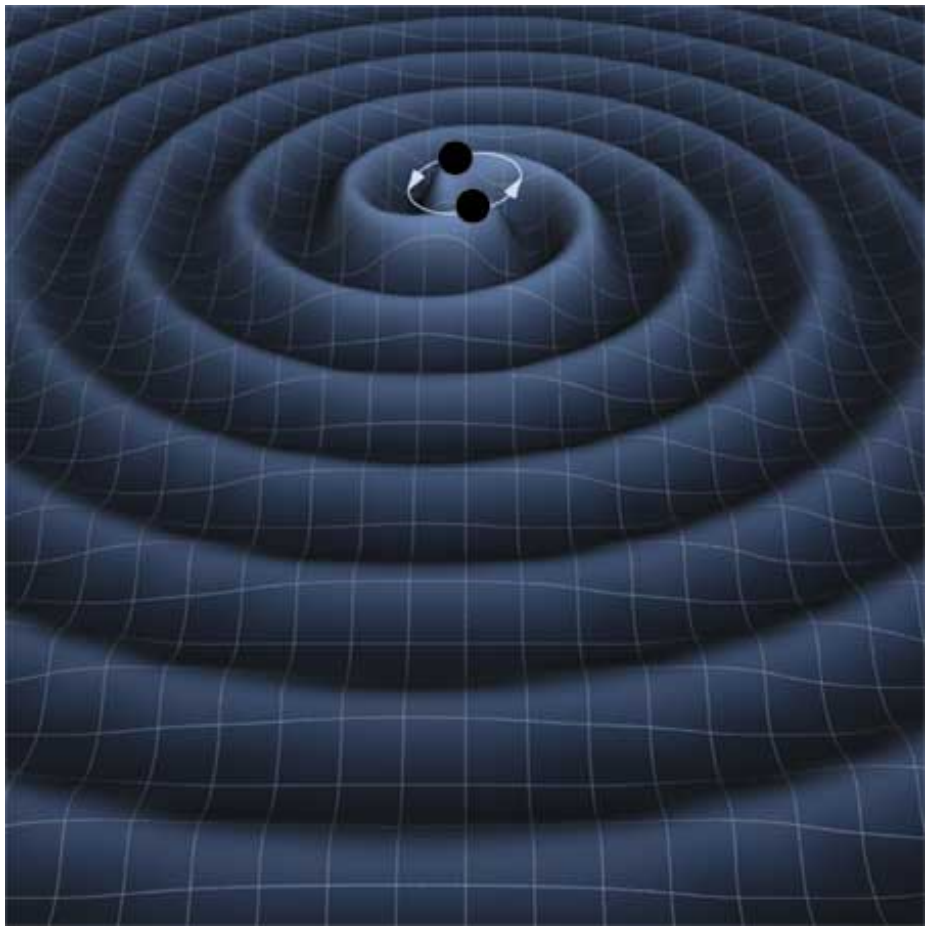
Space tells matter how to move.
Matter tells space how to curve.
– John A. Wheeler



http://preposterousuniverse.com/spacetimeandgeometry/covercrop.jpg
http://zebu.uoregon.edu/ph121/hb/amy/merc.jpg

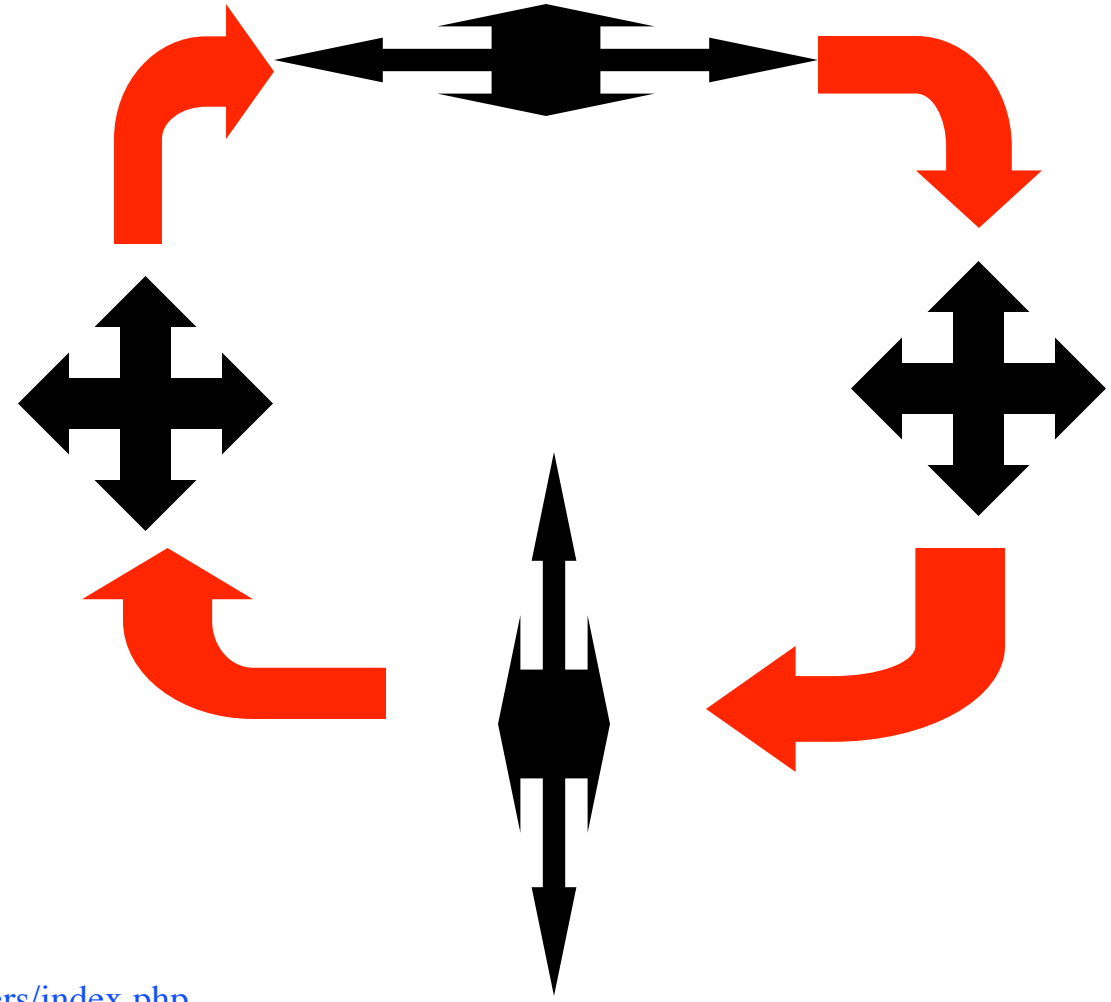
What is a Gravitational Wave?

- Change in matter distribution = Change in curvature
- Propagating change in curvature = A Gravitational Wave



http://lisa.jpl.nasa.gov/gallery/binary-wave.html

What is a Gravitational Wave?



Animation from http://www.ligo-la-caltech.edu/Posters/index.php

Gravitational Waves are Small!

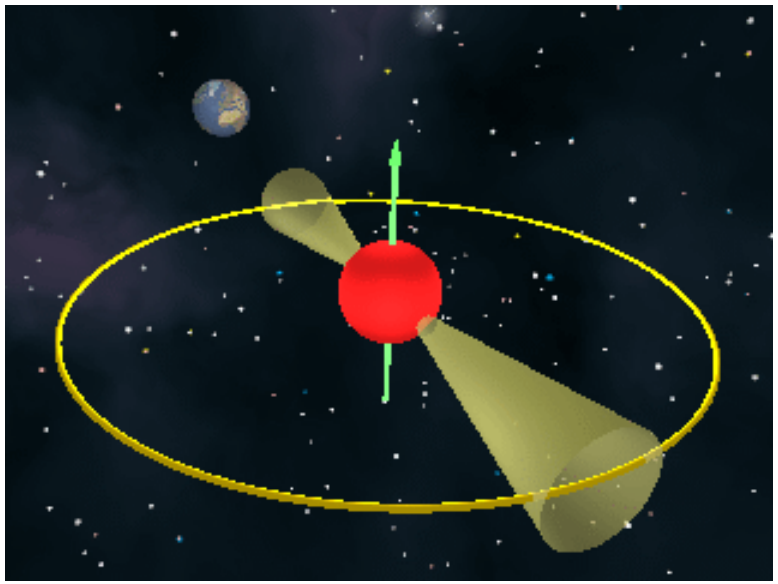
Gravitational Waves Measured in Strain

$$h = \frac{\Delta L}{2L}$$

$$h_{\max} \sim 10^{-21}$$

$$\Delta L = 2D_{\text{Earth}}(10^{-21}) \approx 1 \times 10^{-14}$$

How Do We Know Gravitational Waves Exist?



http://www.jb.man.ac.uk/news/neutronstar/neutronstar.gif

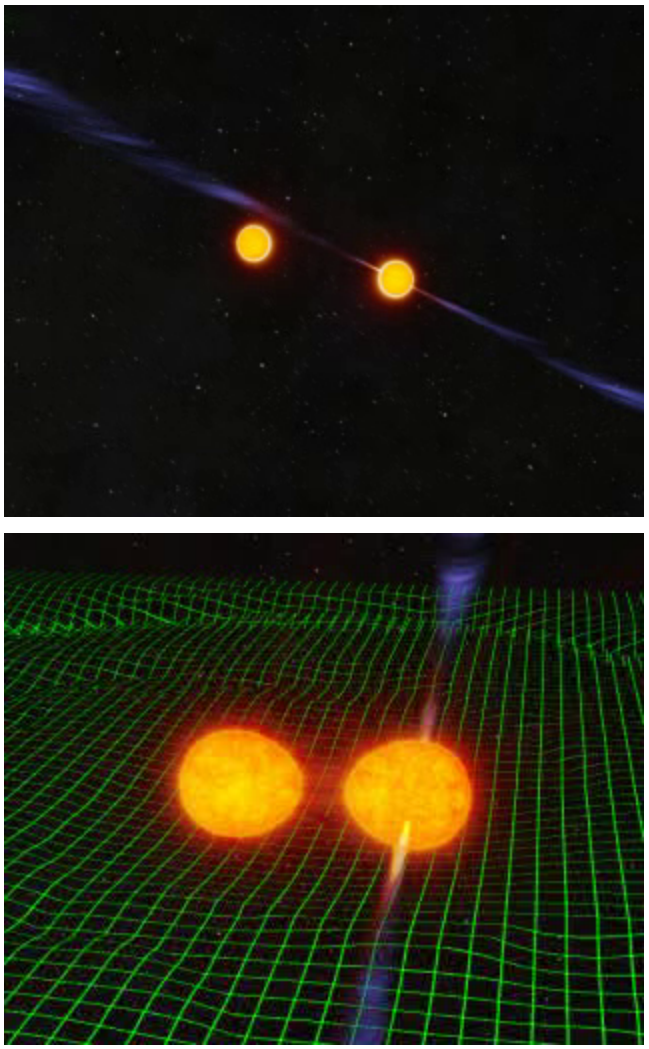
http://nobelprize.org/nobel_prizes/physics/laureates/1993

Hulse

Taylor

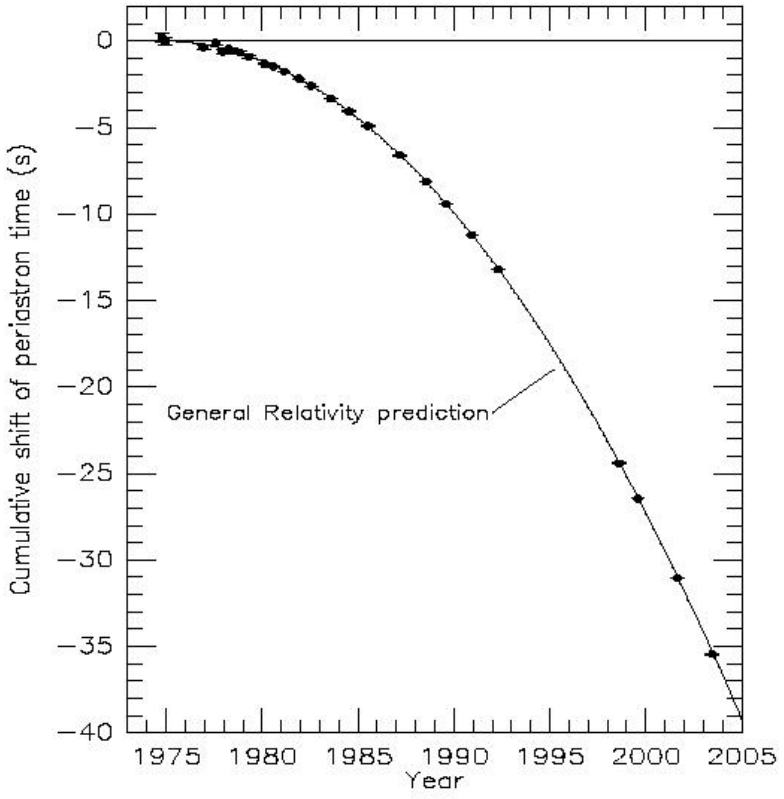
In 1974, Russell Hulse and Joseph Taylor discover a new pulsar

The Hulse-Taylor Binary Pulsar

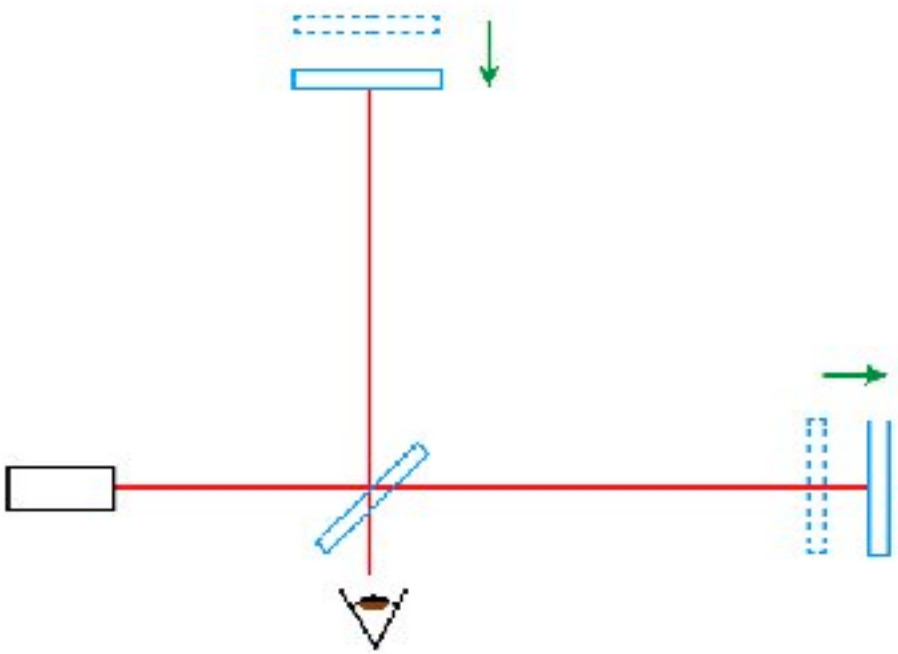


http://www.atnf.csiro.au/news/press/neutron_binary/

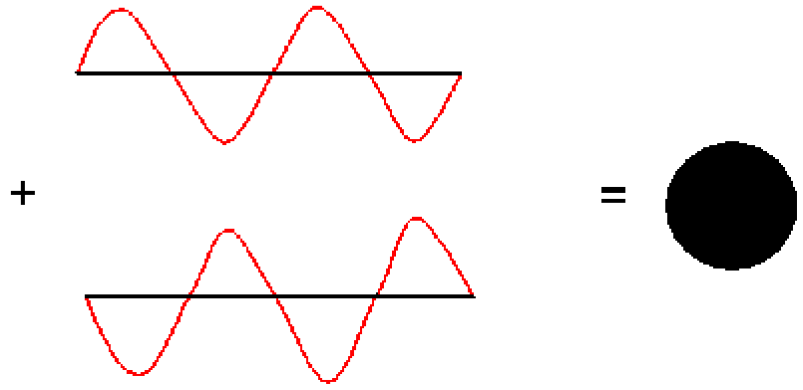
http://arxiv.org/abs/astro-ph/0407149

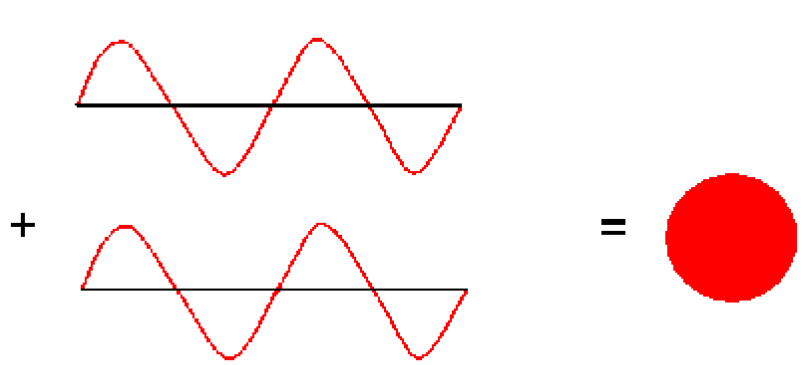


How Do We Detect Gravitational Waves?

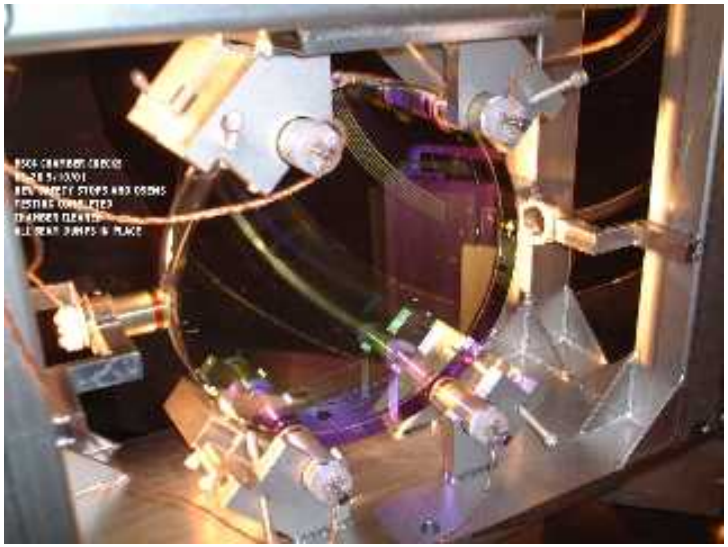


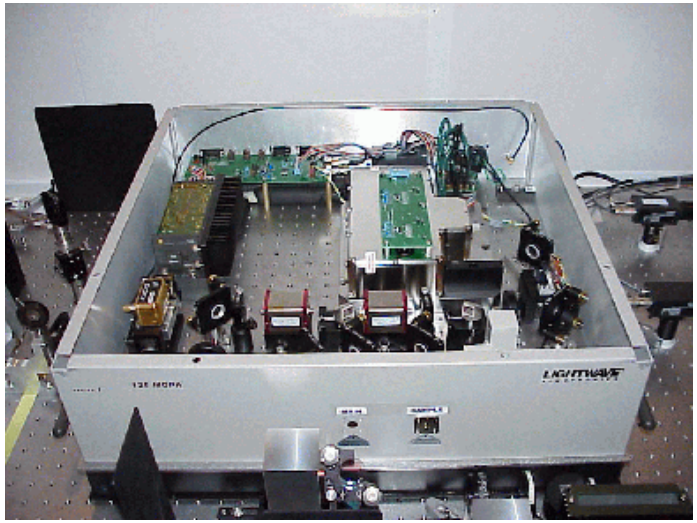
Interferometry





Details! Details!

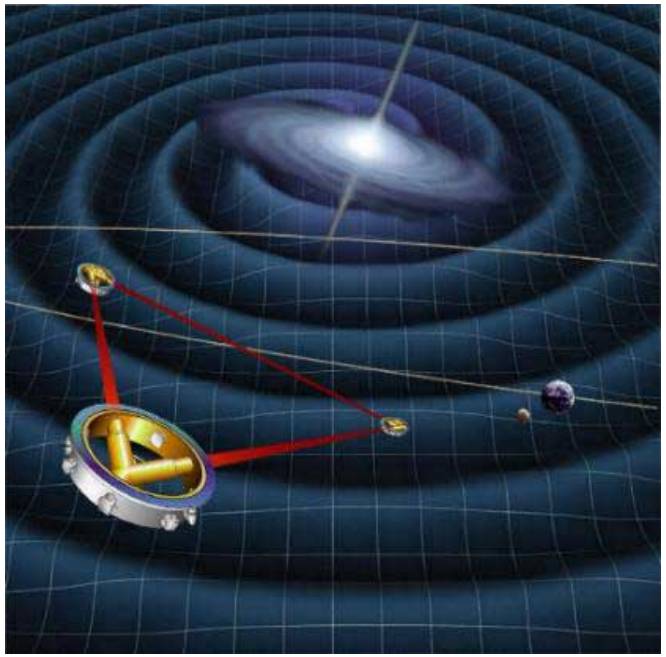


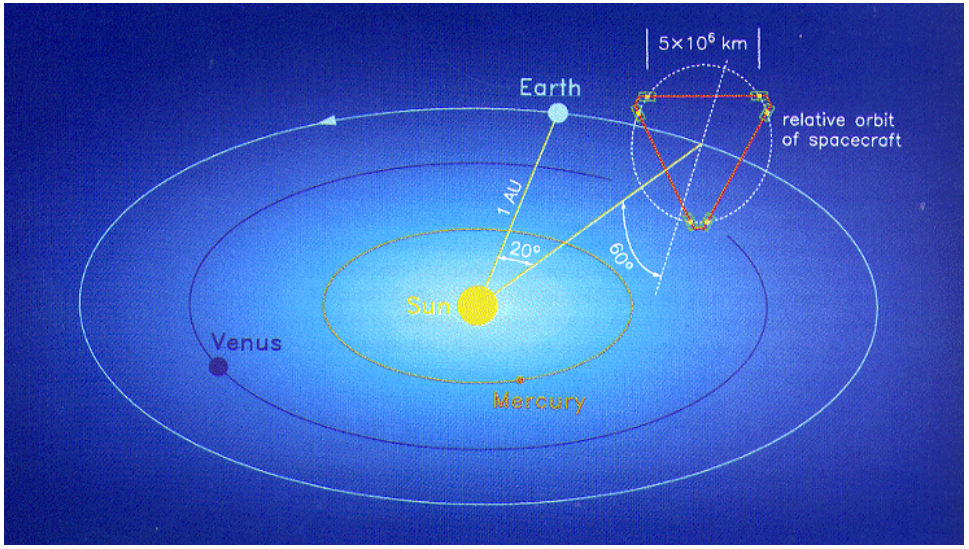


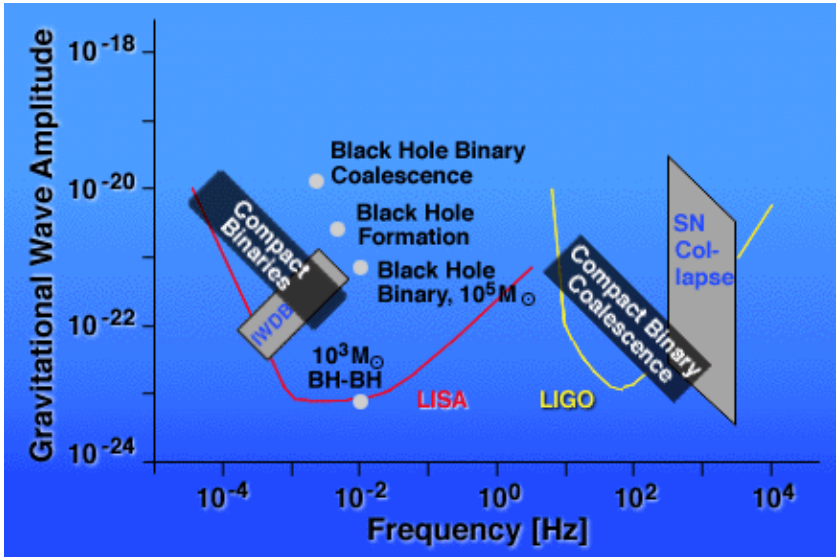
A Network of Gravitational Wave Detectors

http://www.aic.cuhk.edu/web8/world%20map.jpg

Laser Interferometer Space Antenna

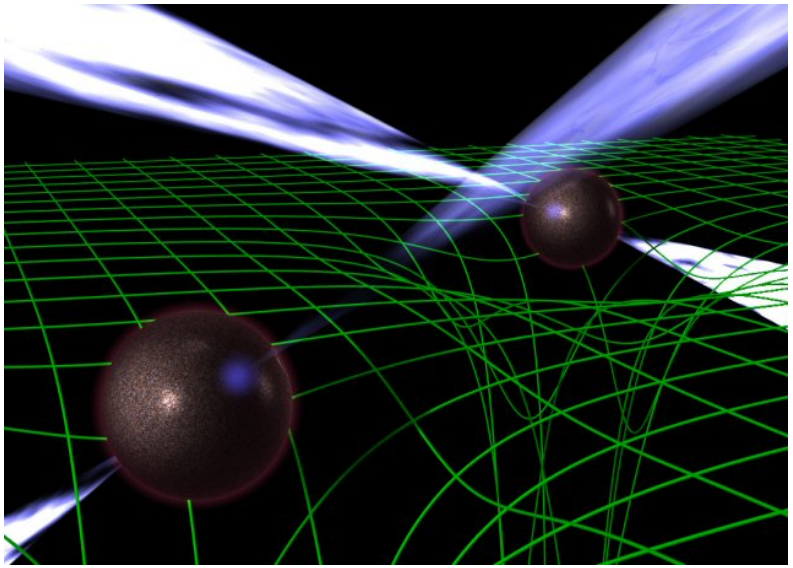






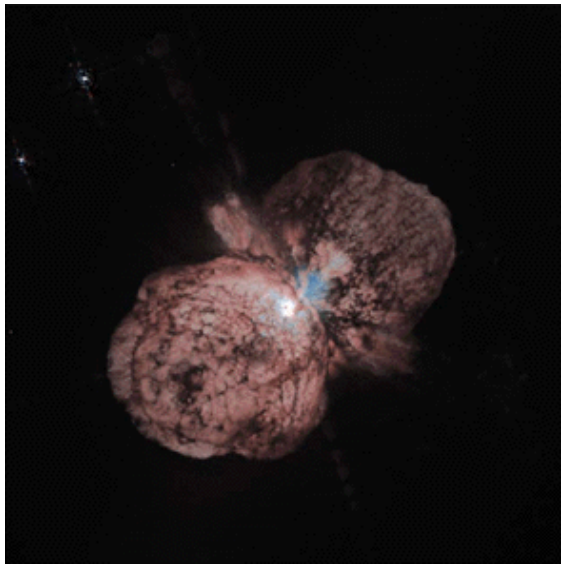
Target Sources

- Binary neutron star inspirals and binary black hole inspirals
- Spinning neutron stars
- Bursts from supernovae etc
- Stochastic background from indistinguishable sources and/ or the creation of the universe

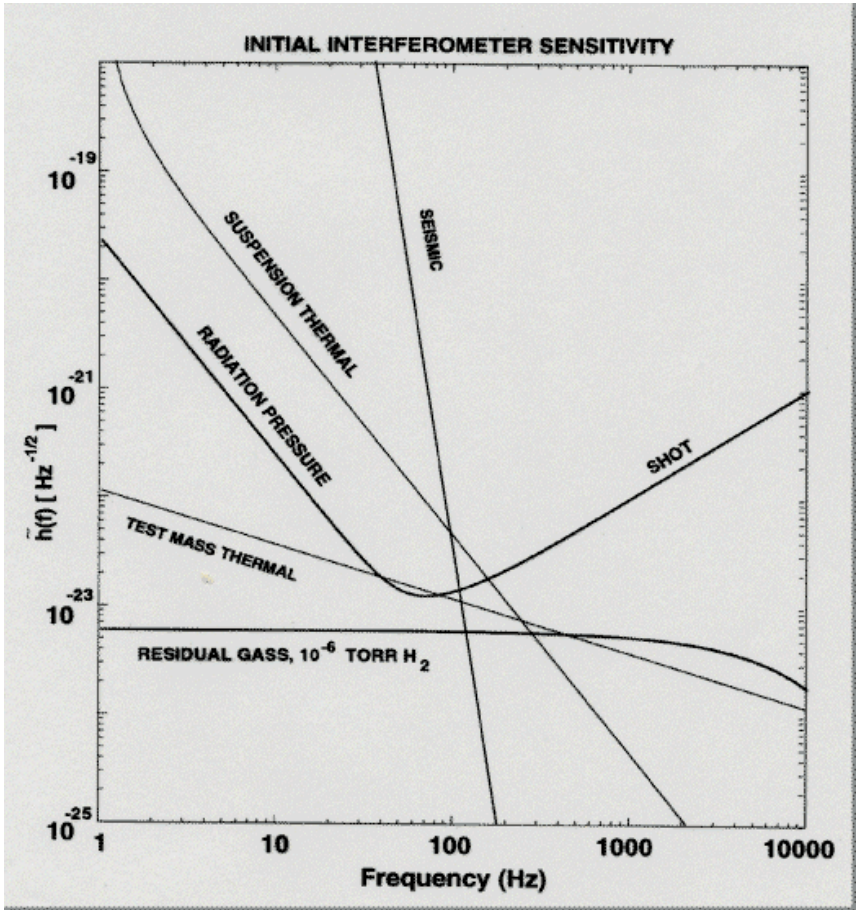


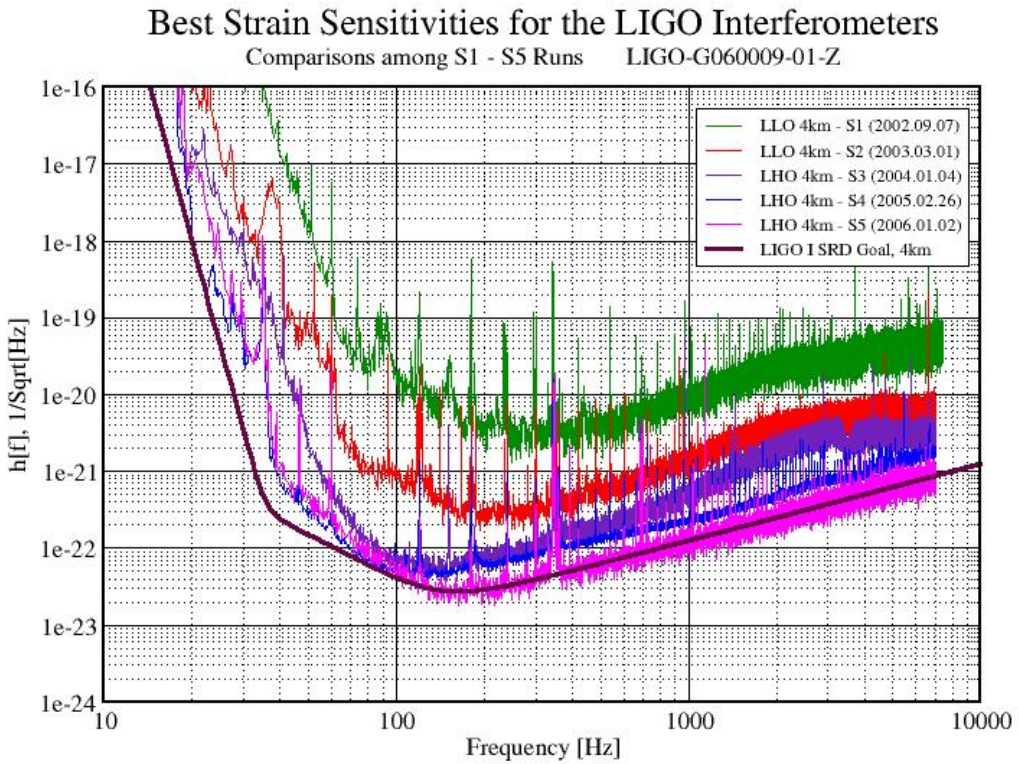
http://www.jb.man.ac.uk/research/pulsar/doublepulsarcd/

http://hubblesite.org/gallery/album/entire_collection/pr1996023a/



How Are We Doing?



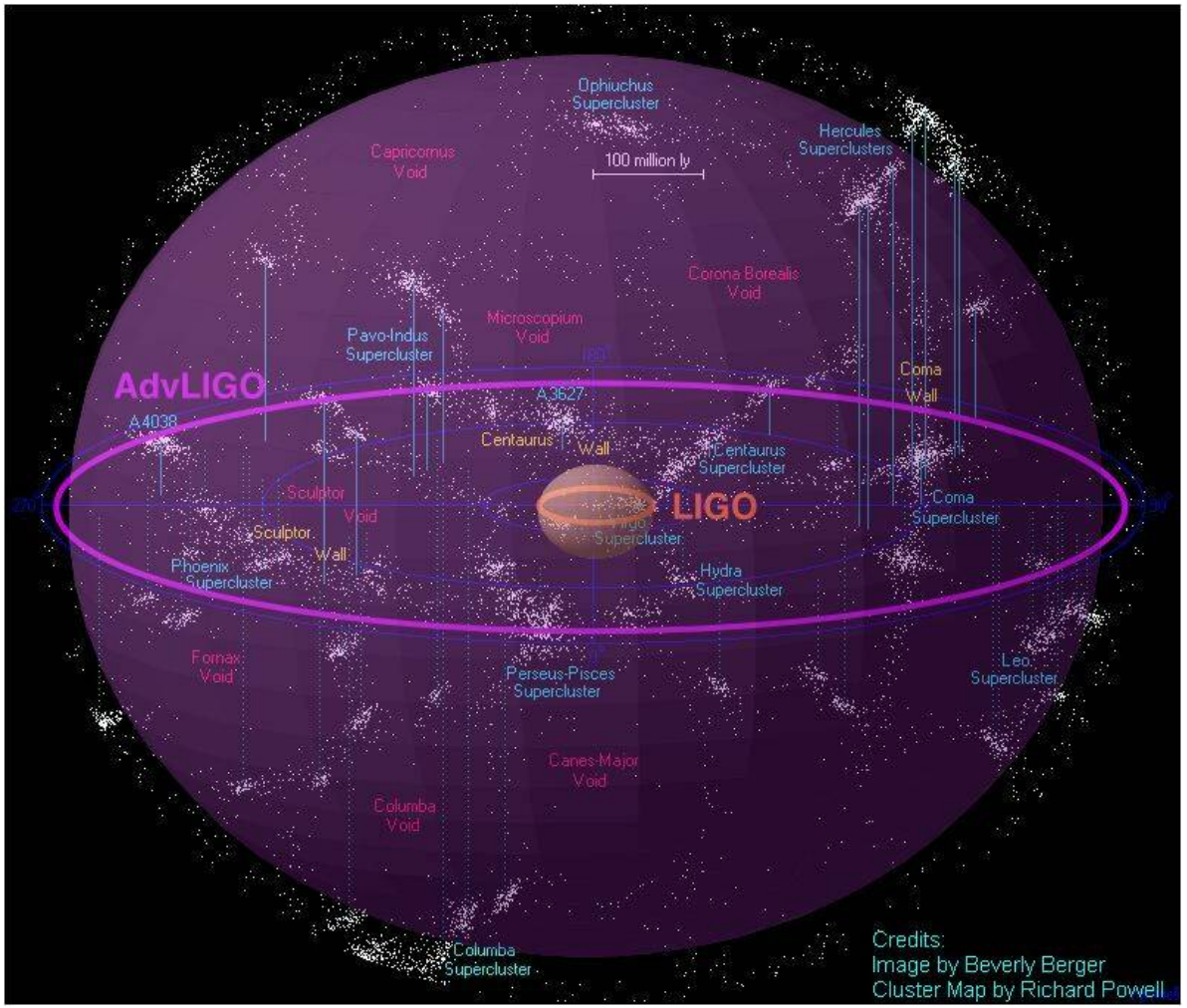


Recent Results Sampler

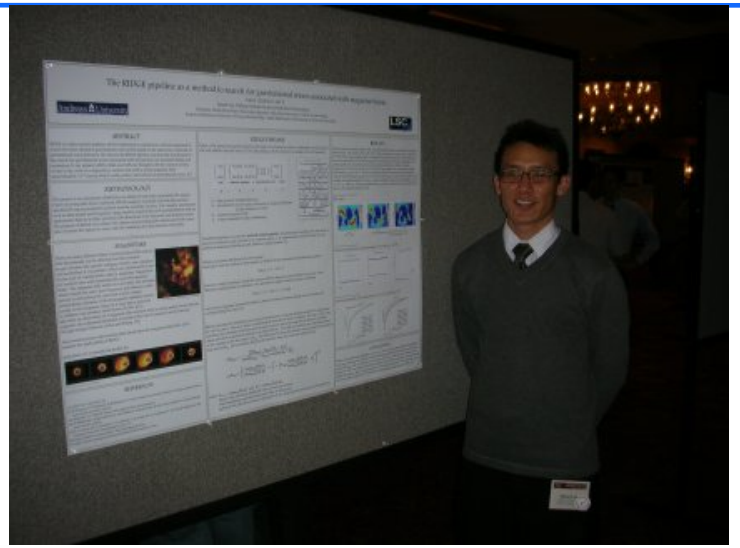
- Astrophys. J. **722** (2010) 1504 arXiv:1006.2535
  - » Limits on the gravitational waves from the youngest known neutron star limit its ellipticity and size of oscillations of material within the star
- Phys. Rev. D**83** (2011) 042001 arXiv:1011.1357
  - » An upper limit of 6.3×10^{-21} to 1.4×10^{-20} (depending on the spherical harmonic excited) is placed on the gravitational wave strain associated with a timing glitch of the Vela pulsar. This constrains the energy release to less than 5.0×10^{44} to 1.3×10^{45} erg.
- Nature **460** (2009) 990 arXiv:0910:5772
  - » The energy density of the stochastic GW background near 100 Hz is constrained to be less than 6.9×10^{-6}. This limit rules out some models of the early universe and some superstring models. The limit exceeds those imposed by Big Bang Neucleosynthesis models and the CMB.
- Many more at https://www.lsc-group.phys.uwm.edu/ppcomm/Papers.html

Coming Soon

- Advanced LIGO
  - » Laser 20W ➔ 200W
  - » Test masses 11kg ➔ 20kg
  - » Suspensions: wire slings ➔ silica fibers
  - » Suspensions ➔ active seismic isolation
- Coming in 2014!

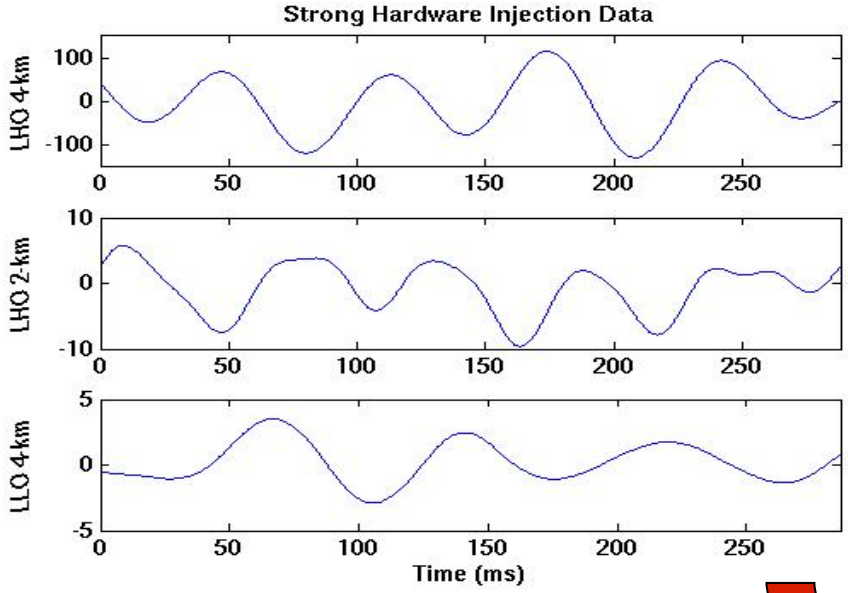


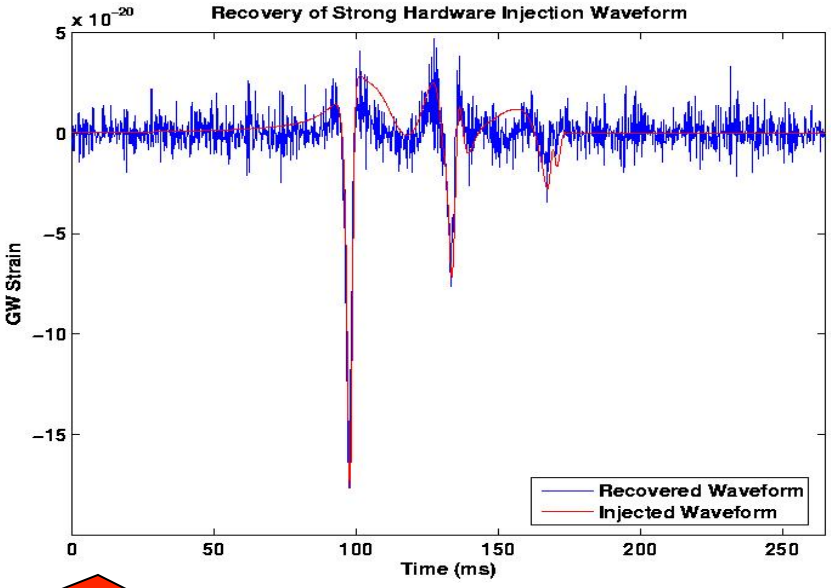
LIGO @ Andrews



LIGO @ Andrews

- Waveform Recovery





PSURG

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Other LIGO Opportunities

- Summer Opportunities
  - » International REU in Gravitational Wave Physics

    http://www.phys.ufl.edu/ireu/
  - » Summer school on Gravitational Waves in Corsica, France
- Join the Search for Gravitational Waves
  - » Einstein@Home http://einstein.phys.uwm.edu/
- Learn More about LIGO
  - » LIGO website http://www.ligo.org
  - » Einstein's Unfinished Symphony by Marcia Bartusiak