Ripples in spacetime

gravitational wave astronomy and what it might tell us

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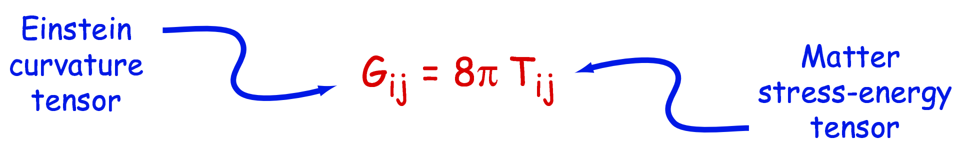
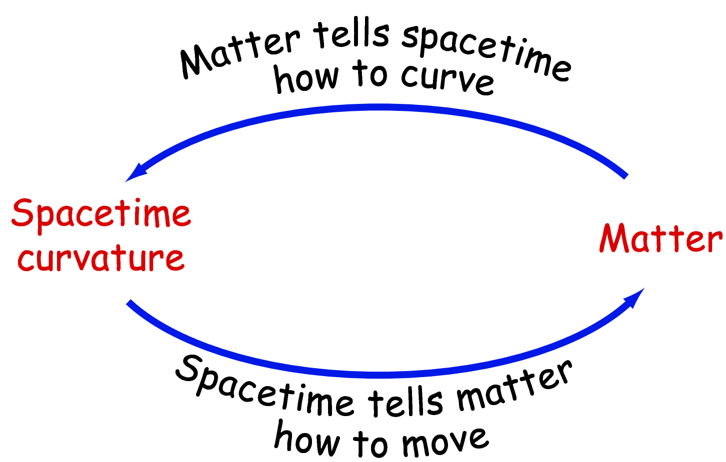
Einstein's equations

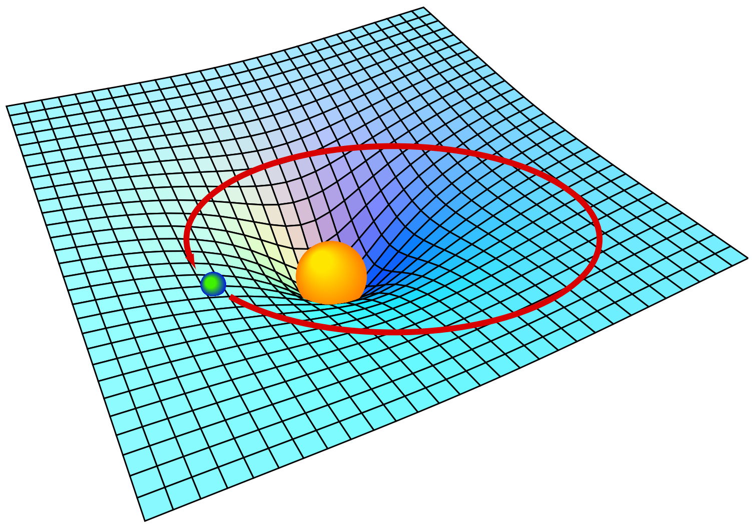
Left-hand side $=$ right-hand side





Spacetime curvature

- A star causes the spacetime around it to become curved.



- Other objects feel the curvature produced by the star and move along the shortest paths in the curved spacetime.

- Photons also follow shortest paths in curved spacetime: bending of light rays passing the sun.

Wave generation

When matter "rattles"
$\longrightarrow$ ripples of curvature $\equiv$ *Gravitational Waves*

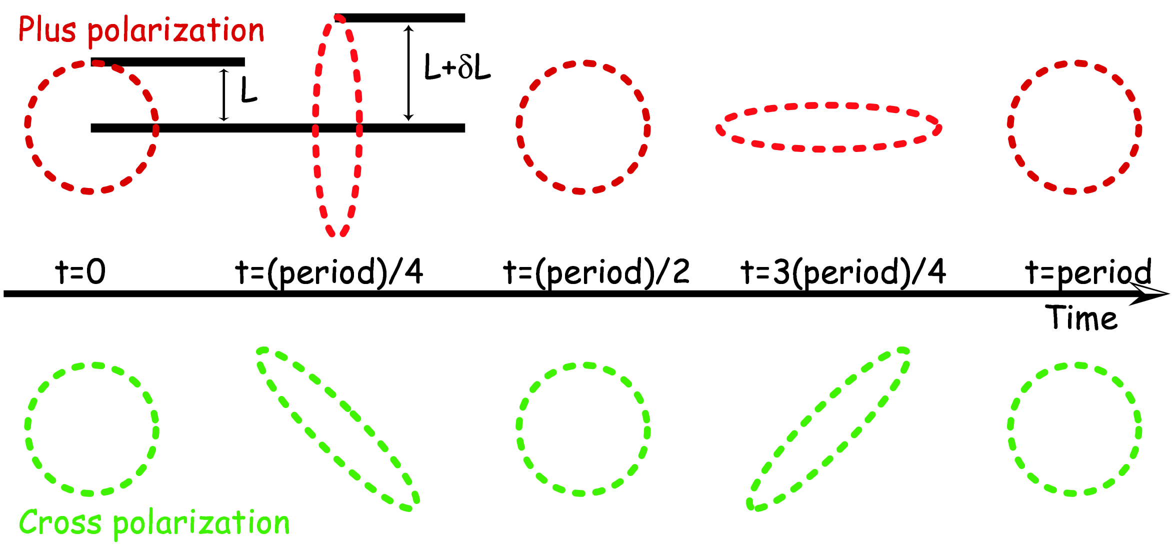
Electromagnetic waves are familiar from the world of everyday experience, and provide a reference point for intuition about gravitational waves. There are differences, however.

Electromagnetic radiation	versus	Gravitational radiation
⇨ oscillations of electromagnetic fields		⇨ oscillations of spacetime geometry
⇨ travels through spacetime		⇨ is part of the "fabric" of spacetime
⇨ emitted incoherently by constituents (atoms, ions, etc.) of astronomical sources		⇨ emitted coherently by bulk motion of astronomical sources or spacetime itself
⇨ has wavelengths much smaller than astronomical source		⇨ has wavelengths comparable to, or bigger than, astronomical source
⇨ gives us "picture-like" description of source		⇨ provides "sound-like" description of source
⇨ is easily absorbed and scattered in transit		⇨ is not easily absorbed or scattered

Physical properties of the waves

- Propagate at the speed of light
- Transverse
- Two polarization states h_+ and $h_\times$

Observational consequences



Ring of particles moving freely—$R_x = R_y = L$

$$\frac{|R_x - R_y|}{L} = F_+ h_+ + F_\times h_\times = h(t)$$

Properties . . . (cont'd)

Physical effects are determined by curvature

$$\text{Curvature} \sim \frac{\partial^2 h_+}{\partial t^2} \ \& \ \frac{\partial^2 h_\times}{\partial t^2}$$

Weak-field limit of General Relativity implies

$$h \simeq \frac{G}{c^4 r}\frac{d^2 Q}{dt^2}$$

The power radiated is

$$P = \frac{G}{5c^5}\left(\frac{d^3 Q}{dt^3}\right)^2$$

Gravitational waves provide a unique probe of strong field gravity, and carry very different information than electromagnetic waves.

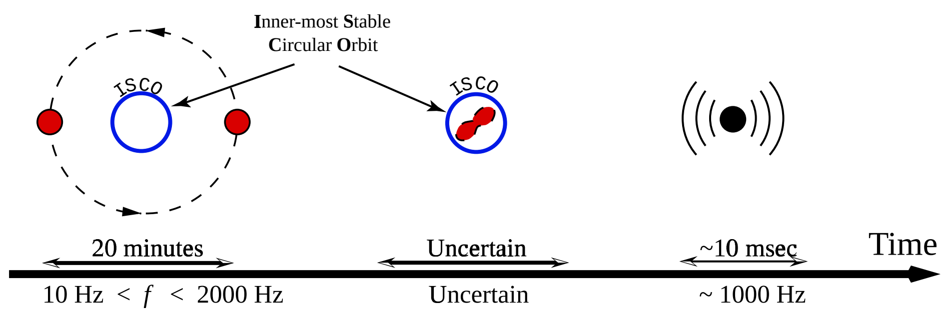
Remember the violent universe that was revealed by Radio astronomy and wonder what a vastly different medium will bring us.

Compact binaries

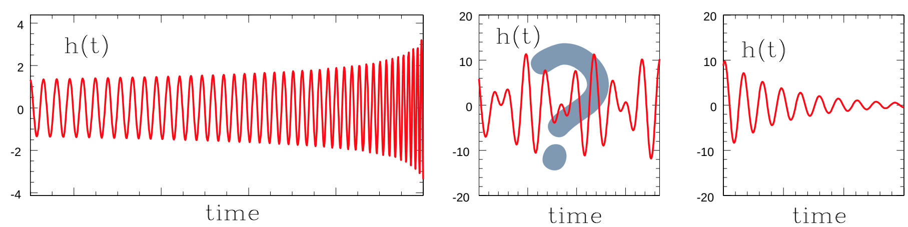
Compact binaries consist of two objects in orbit around each other. There are three flavors of interest to LIGO

- Pairs of neutron stars
- Pairs of black holes
- Black hole and neutron star

As the loose energy as gravitational waves, they elements get closer together.

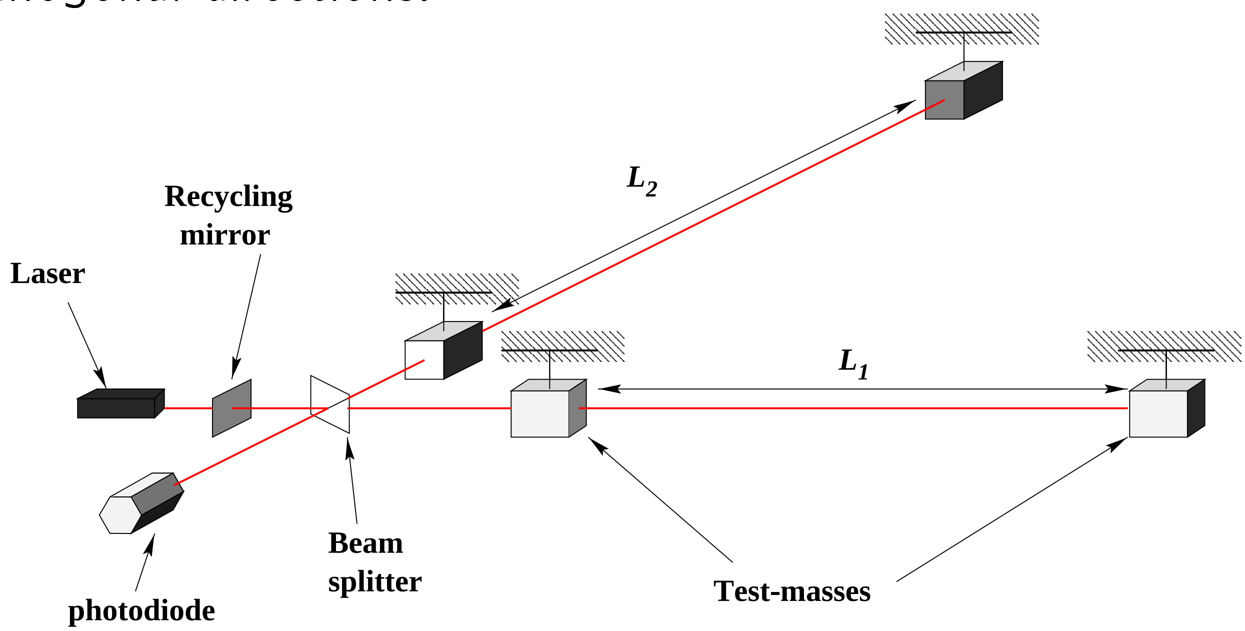


The waves from each phase might look like this:



Laser interferometers

Based on the same principal as the ring of particles — use interferometer to monitor the change in length in two orthogonal directions.



Change in path length is related to change in phase by

$$\Delta L \approx \frac{\lambda \Delta \Phi}{B}$$

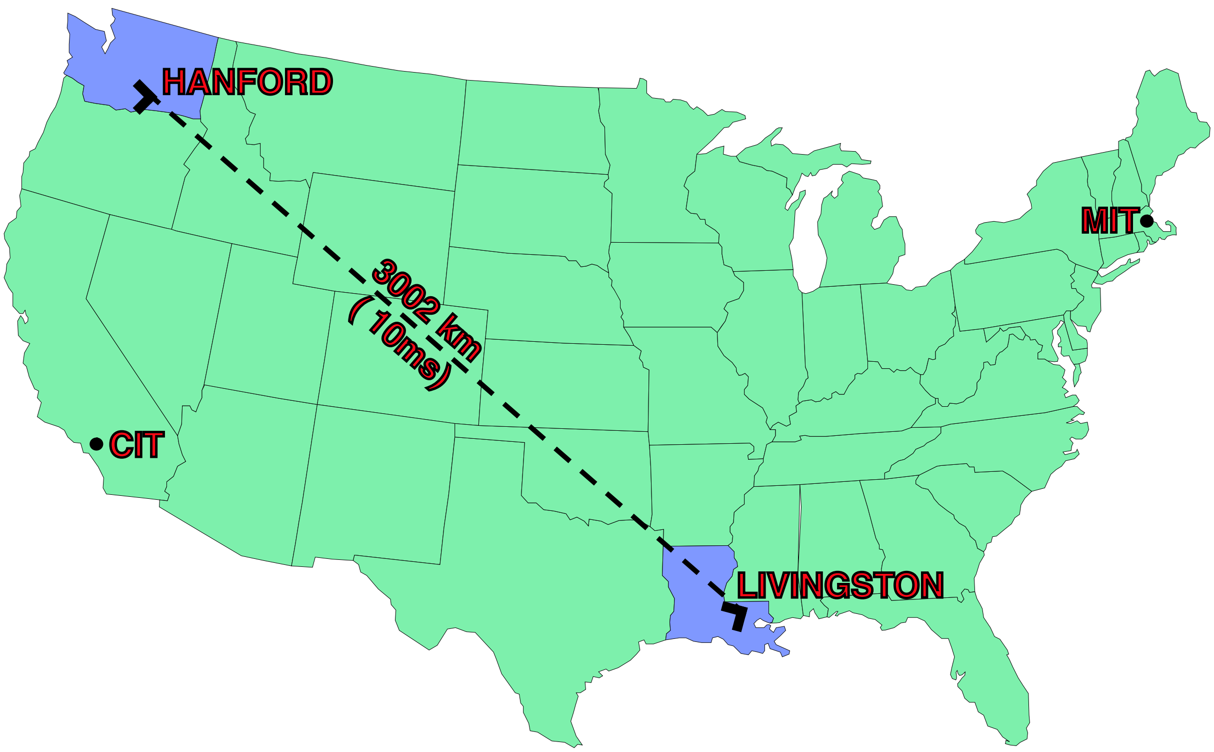
B no. of times light bounces back and forth

λ wavelength of laser light

If the arm length $L = 4$km, then current technology can achieve

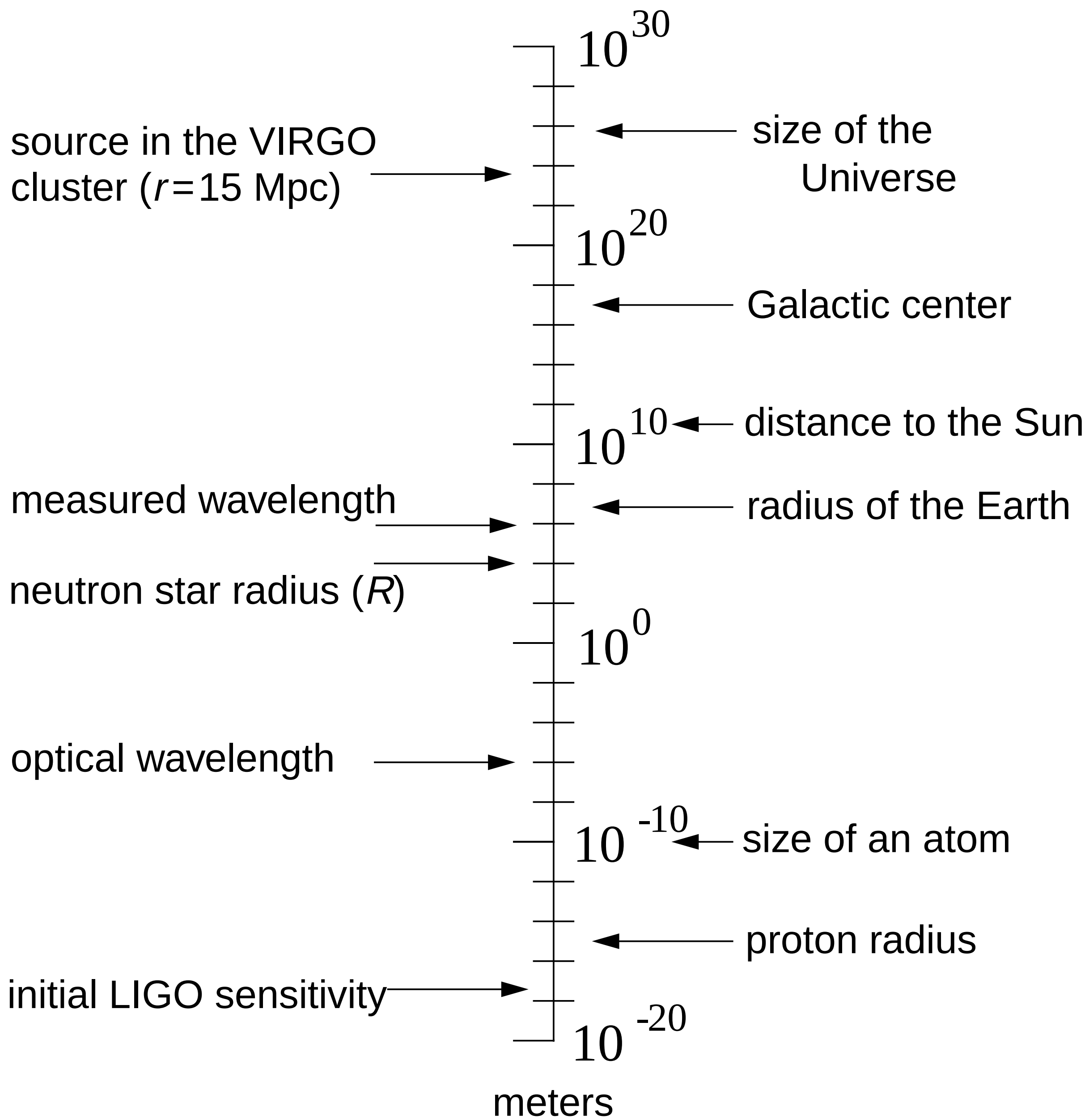
$$\frac{\Delta L}{L} \sim 10^{-21}$$

LIGO consists of three interferometric detectors: one at Livingston (LA) and two in Hanford (WA).



The interferometers have arms that are 4km and 2km in length.

Comparison of scales



LIGO: the count-down to science

Current activities

- The 2km interferometer at Hanford has been taking data for the past 24 hours. First test with full scale interferometer.
- Moving ahead with the 4km interferometers at Hanford and Livingston
- First science run 2002-2004: 1 year of coincident data

First science?