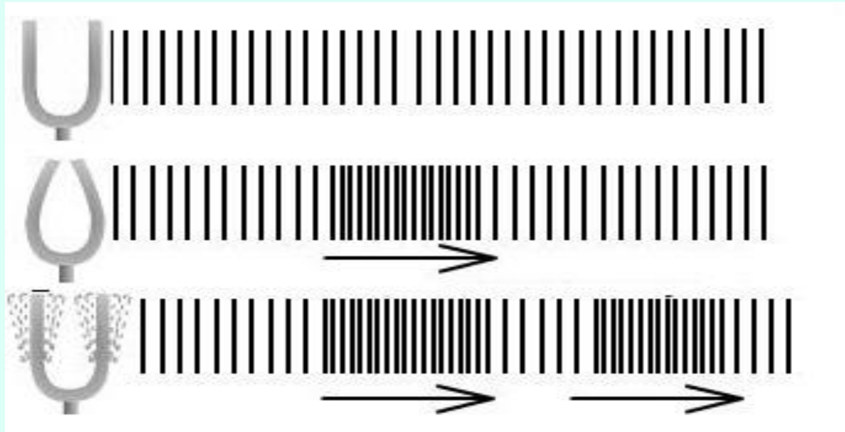
Gravitational Waves
(Ripples in Space –Time)

What are Gravitational Waves??

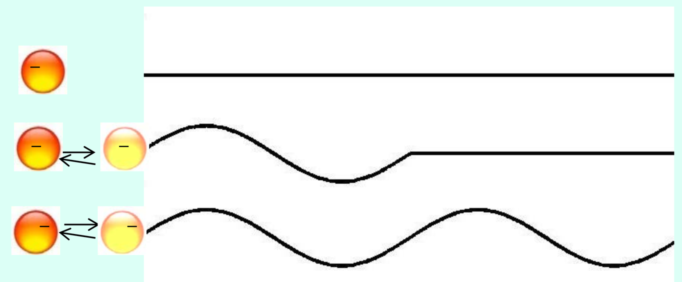
Sound Wave



Consider air as a series of layers. When a tuning fork is static the layers are equally spaced. But when the fork starts vibrating, it creates a disturbance in the air layer beside the tuning fork. That disturbance propagates through the layers at the velocity of sound. If you stand at any place in the medium you will find that the air is getting compressed and rarified as a function of time. So you will find that a wave is propagating through the medium.

❖ Acceleration of the fork creates the sound wave

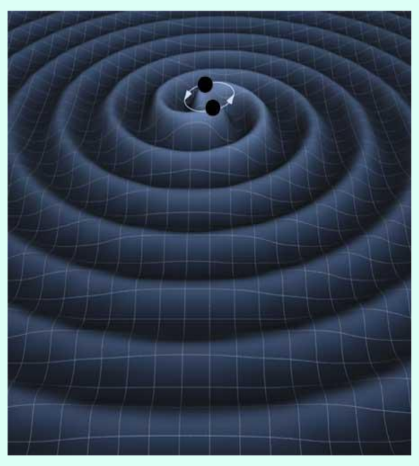
Electro-Magnetic Wave



A fixed electric charge creates an electric field not varying with time and given by the Coulomb's law. If the charge accelerates, then the electric field will also change accordingly and that change will move through space at a velocity **c**, the speed of light. Now a magnetic field will also be present with this varying electric field. The electric field and magnetic field together form the electromagnetic wave.

❖ Acceleration of the charge gives EM wave

Gravitational Wave (GW)



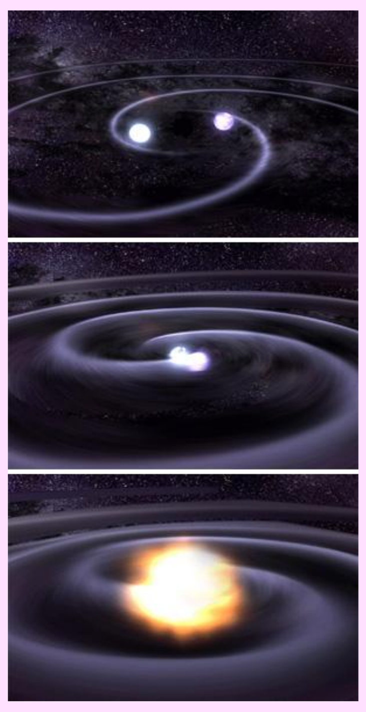
If a mass system accelerates (asymmetrically) then the gravitational field of that system will fluctuate and the fluctuations will propagate through space. These fluctuations form the gravitational wave.

The speed of a gravitational wave is the same as the speed of light. Effect of gravitational waves on matter is very weak and thus we can only expect to see waves from very strong sources .

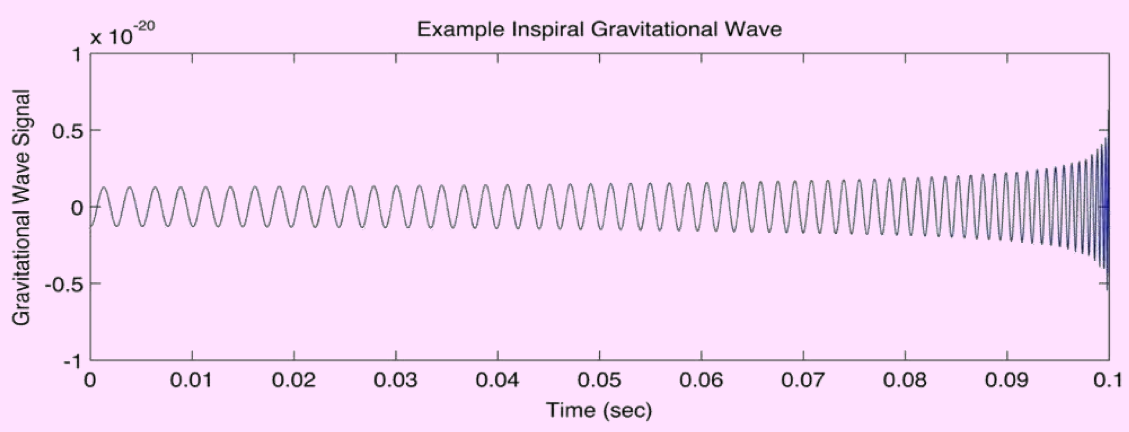
❖Acceleration of masses gives GW

What can Gravitational Waves tell us??

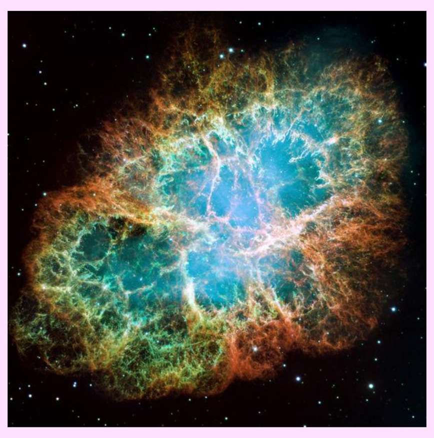
What happens when stars coalesce?



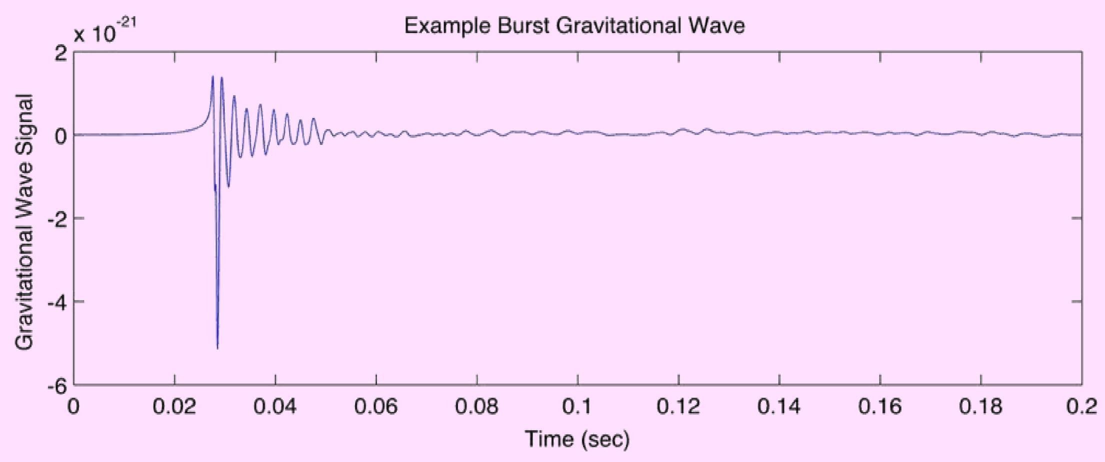
Inspiralling pairs of black holes and neutron stars will emit GW. As the two masses revolve around each other, the distance between them decreases and their speeds increase, causing the frequency and amplitude of the resulting gravitational waves to increase until the objects collide, giving a characteristic "chirp" signal. Thus, GW can give us information on the last stages of the merger.



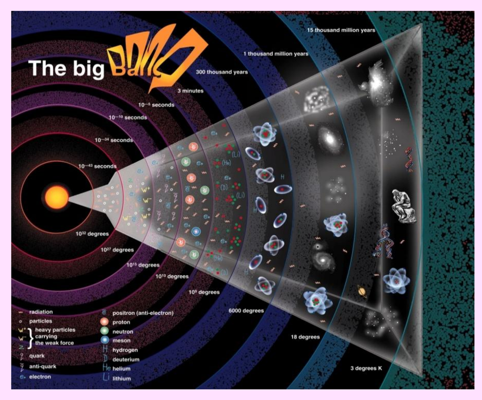
What happens when a star explodes ?



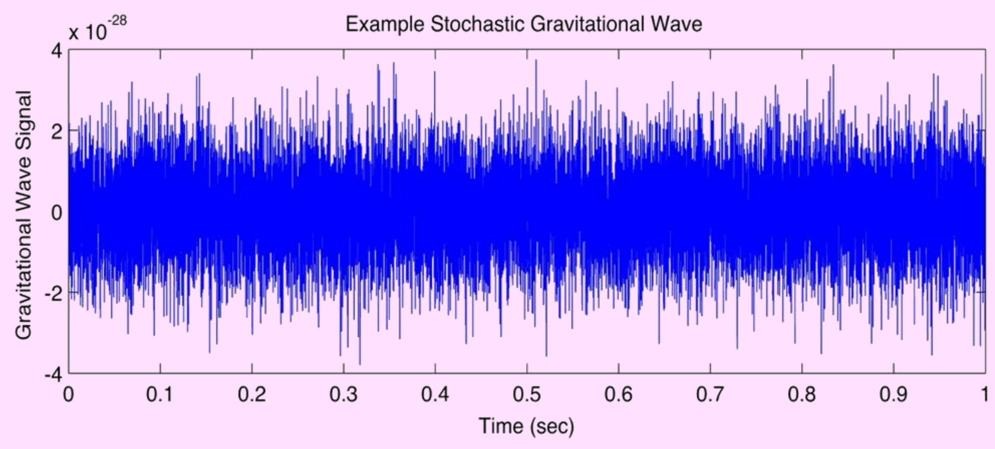
Scientists predict that explosive events such as supernovae and gamma ray bursts may produce bursts of gravitational waves. The exact form these waves will take, however, is still a mystery. The Crab Nebula (left) is the remains of a supernova observed on Earth in 1054, and in its center is a pulsar, which is another potential source of gravitational waves.



What powered the Big Bang?

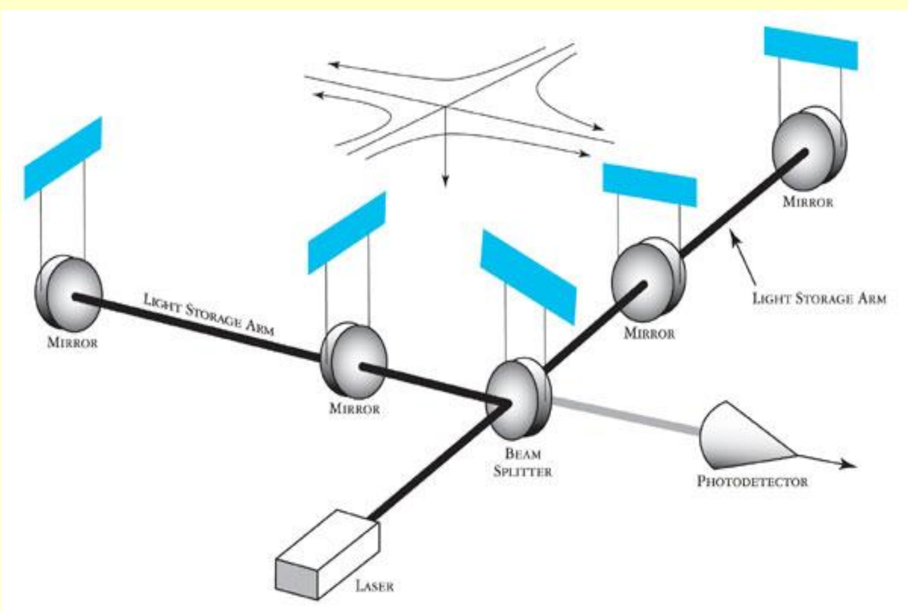


Gravitational waves can give us a window to the beginning of the universe. Earliest light that reaches us was produced when the universe was 300,000 to 400,000 years old , but scientists believe that GWs produced less than a second after the Big Bang are present around us.



How can we see Gravitational Waves ??

Physicists expect gravitational waves to stretch space in one direction and compress it in another. Therefore, most gravitational wave detectors have two arms of equal length at right angles to each other. A single laser beam is split at the intersection point of the two arms. Mirrors are suspended at the end of each arm and near the beam splitter. Laser light in each arm bounces back and fourth between these mirrors and finally returns to the intersection, where it interferes with light from the other arm, and the pattern it creates tells us about gravitational waves falling on the detector, and thereby objects in the universe.



If the lengths of the two arms remain unchanged, the light waves should completely cancel each other out. However, if a gravitational wave were to slightly (about 1/1000 the diameter of proton) stretch one arm and compress the other, the two beams would no longer completely cancel each other, yielding light patterns at the photo detector. Encoded in these light patterns is the information about the gravitational waves.

Indirect detection of the gravitational waves

Existence of gravitational waves has been proved indirectly by R.A. Hulse and J.H. Taylor. In the binary pulsar system PSR 1913+16, the period was found to decrease due to loss of orbital energy due to GW. The measured decrease is 14 sec from 1975-94 and has been measured to ~50 msec accuracy. They were awarded the Nobel prize in 1993. Direct detection of gravitational waves is yet to happen, and when it happens is sure to garner another Nobel prize.

The Detectors

The Laser Interferometric Gravitational-Wave Observatory, or LIGO, is the world's largest gravitational wave observatory, whose arms are 4 kilometers in length. LIGO's detectors are located in Hanford, Washington (top) and Livingston Lousiana (bottom). Other gravitational wave detectors include 3km VIRGO in Italy, GEO600 in Germany, TAMA300 in Japan. The possibility of a similar detector in India is being explored.

Why multiple detectors?

Multiple detectors are necessary to reliably get the gravitational wave signal hidden inside disturbances caused by local sources, like the earth's seismic activity, trees falling in the woods etc , that can appear similar to gravitational waves in the data that is collected. Also because gravitational waves are expected to travel at the speed of light, so there will be delay in time when they are observed at different detectors. Using this delay, scientists will be able to pinpoint the location of the source in the sky.

Location of detectors around the world