Black Holes Basics

Black holes are infinitely dense entities. There are two types...

- Stellar Black Holes come from the collapse (death) of massive stars and have masses from 5 to 30+ times more massive than the Sun
- Supermassive black holes are in the centers of galaxies and have masses from hundreds of thousands to billions time more massive than the Sun

They emit no light as their gravitational forces are so strong not even light can escape. We can 'see' them indirectly...

- Since black holes are massive enough to bend light with gravitational forces, they can be observed by viewing the distorted light traveling to Earth from behind them.
- Objects can orbit black holes according to the laws of gravitation. The supermassive black hole at the center of the Milky Way galaxy is 'observed' via tracking the orbits of stars around it.
- Orbiting and coalescing black holes emit gravitational waves (see below) that can be directly measured on Earth.

While the mass of (the amount of matter in) a black hole can be determined with the above techniques, the physical size (space occupied) is not defined...

- The size of a black hole can be defined to be a singularity, meaning it becomes so small that the density of the black hole becomes infinitely large.
- The size can also be defined by the radius to the event horizon (Schwarzschild Radius), which is the distance from the black hole at which objects (light, for example) crossing this threshold will not be able to escape the gravitational force exerted by the black hole.

Gravitational Wave Detection

Gravitational waves are very difficult to detect

- Gravitational waves were originally predicted over 100 years ago as part of Einstein's Theory of General Relativity.
- Building detectors sensitive enough to detect gravitational waves took over 40 years of design and enhancement. This is because gravitational waves only create a small distortion in space time that needs to be measures to the precision of 10,000 times smaller than a proton.
- Gravitational waves detectors need to be very large. LIGO (Laser Interferometer Gravitational wave Observatory) uses two detectors (both in the US), with each detector equipped with 4 km long interferometers. An additional detector called VIRGO is in Italy.

Scientists are steadily making Gravitational Wave detections.

- As of July 2018, five black hole-black hole detections and one neutron star – neutron star detection have been confirmed
- The first detection of a black hole merger was made on 14 September 2015 at the LIGO observatories. Both observatories detected the gravitational wave signal.
- The first detection of a neutron star merger was make on 17 August 2017. This detection was made in both gravitational waves and in the electromagnetic spectrum as neutron stars do emit light.
- The neutron star merger resulted in a large release of electromagnetic energy called a kilonova and introduced a new field of astronomy now called multi-messenger astronomy.

Gravitational Waves: What Are They?

Gravitational Waves are ripples in the fabric of space-time.

- All objects in the universe exist within the four-dimensional system of space-time (three dimensions of space and one dimension of time). However, it is easier to imagine it as a two-dimensional fabric sheet.
- Very massive objects create distortions in (bend) the fabric of space time. Other objects respond to these distortions and follow the curves of space-time.
- *'Spacetime tells matter how to move; matter tells spacetime how to curve'* - John Archibald Wheeler

Gravitational waves are the result of very energetic interactions in the universe.

- Large stellar remnants (such as black holes or neutron stars) orbit and spiral in toward each other and eventually coalesce, creating a large release of energy
- This energy is plentiful enough to create ripples in space-time, similar to how a rock colliding with the surface of the water will generate water ripples that travel away from the point of collision.
- Gravitational waves travel at the speed of light.
- Gravitational waves have a particular size (amplitude) and shape depending on the properties of the objects that coalesced