White Dwarfs

- A white dwarf is the endpoint of our Sun’s evolution, and from single stars whose mass is less than about 5–8 $M_\odot$.
- Typical masses are from 0.3 – 1.3 $M_\odot$
- Typical radii is the Earth’s radius
- White dwarfs are composed of Helium, or Carbon and Oxygen
- The maximum mass for a white dwarf is 1.4 $M_\odot$, the Chandrasekhar Mass
- Pressure support in a white dwarf is from *degeneracy* pressure, not the *thermal* pressure important in the Sun. Degeneracy pressure comes from the quantum mechanical principle, the *Pauli Exclusion Principle*, which prevents certain subatomic particles like electrons from crowding too close together.
- If too much mass is added to a white dwarf, it will collapse and explode from the release of thermonuclear energy. This is called a Type I supernova.
Neutron Stars

- Neutron stars are endpoints of stars whose masses are greater than 5–8 M⊙
- Typical masses are about 1.3 – 1.5 M⊙
- Typical radii are about 12 km, 1000 times smaller than a white dwarf
- Interior densities are greater than inside atomic nuclei. Most matter is therefore not nuclei, but nucleons – about 90% neutrons and 10% protons
- The maximum mass for a neutron star is estimated to be about 2–2.5 M⊙
- Pressure support due to nucleon, not electron, degeneracy pressure
- Too much mass added to a neutron star forces a collapse to a black hole
- Most observed neutron stars, about 2000, are pulsars which are highly magnetized and rapidly rotating (up to 700 times a second)
- Neutron stars are observed at the centers of many supernova remnants. They originate from supernovae (Type II)
Black Holes

- Black holes are so dense that their escape velocity is greater than the speed of light – nothing can escape
- The radius of a black hole has a simple relation with its mass:

\[ R = \frac{2GM}{c^2} \quad \text{or} \quad R (\text{km}) \approx 3 \ M_{\odot} \]

The \textit{Schwarzschild Radius}, forms an \textit{event horizon} – we cannot see inside
- The center of a black hole has a singularity at which the strength of gravity and the curvature of space and time is in principle infinite
- Believed to be formed in some supernova explosions, when remnant mass is too great for a neutron star
- Black holes of 5 – 30 \( M_{\odot} \) are observed in several binary stars. Masses can be measured using Kepler’s laws
- Black holes are also believed to exist at the centers of most galaxies, with masses typically millions of \( M_{\odot} \)
A common misconception is that a black hole is like a giant vacuum cleaner – in fact, extremely large gravities exist only very near the surface. If the Sun were a black hole, the Earth would orbit it the same way it does now.

In contrast to a star, where the gravity decreases to zero at their centers, gravity increases within a black hole.

Objects near a black hole are torn apart by tidal forces.

From our perspective, objects falling into a black hole get redder and take forever to fall in. A person on the falling object would measure a finite infall time, however.

The notion that *wormholes* connected with black holes could be pathways to other parts of our universe or other universes is – speculation and science fiction.