Life and Death of Stars

Properties of Stars

Stars are balls of gas.

Gas has three main properties:
- Pressure
- Temperature
- Density

Temperature and Particle Speed
- Higher temperature => faster particles

Longer arrows mean higher average speed.
Recall: Conditions inside the Sun

• The higher the temperature, the faster the particles go.
• Less massive particles go faster than more massive ones.
• The faster the particles go, the greater the pressure.

Earth example: hot air balloon

Density

• Density = Mass per unit Volume.
• Mass is related to, but not the same as weight.
• Weight depends on gravity, mass does not.

Temperature, Pressure, Density

In general, for normal gases, if one increases, the others increase as well.
Stars condense from clouds of gas and dust (the interstellar medium) that exist throughout the disk of the galaxy.

Interstellar medium
  Gas = Hydrogen
  Dust = Carbon and Silicon

Becoming a Star Step 1 – Cloud collapses

• Why do these clouds of gas and dust collapse?
  One idea is that a shockwave from the explosion at the death of a star known as a supernova cause the gas and dust cloud to become unstable and start to collapse.

Becoming a Star Step 1 – Cloud collapses

• As the cloud collapses, the center becomes very very hot and very very dense.
As the gas cloud collapses due to gravitational forces, the core becomes hotter and the density inside the core increases.

Eventually, the temperature and density reach a point where nuclear fusion can occur.

Fusion is the combining together of light atoms, into heavier atoms.

For all Main Sequence stars, the temperature and density in their cores are so great that hydrogen atoms combine to make helium atoms and release energy—a process known as thermonuclear fusion:

\[ 4H \rightarrow He + \text{energy} \]

Becoming a Star Step 3 – Balance!

All Main Sequence stars are in hydrostatic equilibrium:

- Fusion produces radiation (light) that creates an outward pressure.
- During hydrostatic equilibrium there is a balance between the gravitational collapse of the star pushing inward and the outward pressure produced by photons from nuclear fusion in the core.
It’s a matter of balance.

- This balance is called **hydrostatic equilibrium**
- **Gravity** \( \leftarrow \) wants to collapse the star, but
  **Pressure** \( \rightarrow \) pushes outward against the collapsing material

Fusion: \( 4H \rightarrow He + \text{energy (light)} \)

- All Main Sequence stars are in hydrostatic equilibrium because nuclear fusion of hydrogen is producing enough outward pressure to balance gravitational collapse.

It takes a few million years to get there but - stars spend most of their life time as a Main Sequence star
Stars spend most of their life time as a Main Sequence star

- 90% of the whole life of all stars is spent on the Main Sequence
- 90% of all stars are found on the Main Sequence

Stars often form in pairs called “Binary Stars”

- These stars can orbit each other much like a star and a planet, and in some cases the stars pass in front of each other - we call these “Eclipsing Binary” stars

Class Action!

An evolutionary track is shown in an HR diagram below. A track like this corresponds to...

(A) the motion of a star through space
(B) the evolving characteristics of different generations of stars
(C) the characteristics of one star changing over time
(D) the characteristics of a group of stars at one time
(E) none of the above
Stellar Evolution

- The life of a star depends on its mass
- Most stars can be put into three evolutionary categories according to the star’s mass.
Lightweight Stars (0.8 – 8 solar Masses)

Mass and evolution

Stars on the Main Sequence are fusing Hydrogen into Helium

The Red Giant Phase

- The core runs out of Hydrogen to fuse into Helium.
- The Helium core contracts and Hydrogen fusion begins in a shell around the core.
- The core is hot enough for the helium to fuse to form carbon. Some helium and carbon fuse to form oxygen.
- The outer layers begin to expand, cool and shine less brightly. Recall: Cooler stars are redder.
Lightweight Stars (0.8 – 8 solar Masses)

Betelgeuse is a red giant

Atmosphere of Betelgeuse

2. Runs out of Hydrogen (after ~10 billion years)
Becomes a red giant

Class Action!

When the sun ascends the red giant branch its...

(A) luminosity increases and temperature increases
(B) luminosity increases and temperature decreases
(C) luminosity decreases and temperature increases
(D) luminosity decreases and temperature decreases
Lightweight Stars (0.8 – 8 solar Masses)

- The Helium fusion process is very sensitive to temperature (T). If T varies by even just 2%, the reaction rate doubles.
- The star becomes very unstable. The Helium fusion gas can expand rapidly and cool, reducing the reaction rate. This process causes pulsations that become so large that the star’s outer gas layers blow off as shells into space. UV light makes the shells glow. These gas shells are called Planetary Nebulae.

Planetary Nebulae

**Red Spider Nebula**

Planetary Nebula: Gas is crushed and heated

⇒ supersonic shocks
massive wave crests

Planetary Nebulae

**Red Spider Nebula**

Planetary Nebula: Waves 100 billion miles high

Like ocean waves, planetary nebulae quickly disperse into the surrounding material.
Lightweight Stars (0.8 – 8 solar Masses)

Class Action!

Toward the ends of their lives, all stars with masses similar to the sun blow their outer layers off into space in what is (deceptively) termed a planetary nebula. Since only about 1500 planetary nebula are known, the expanding shell of debris must be...

(A) faint because it is very small
(B) faint because it is very cool
(C) short-lived since it quickly disperses
(D) shrouded in gas and dust
(E) hidden in the glare of the brighter exposed stellar core

Lightweight Stars (0.8 – 8 solar Masses)

- Lightweight stars don't have enough mass to begin carbon fusion.
- When the Helium runs out, and the outer layers have been blown off in a planetary nebula, the remaining core is called a white dwarf.
- White dwarfs are made of carbon and oxygen.
Size of a White Dwarf

- White dwarfs with same mass as Sun are about same size as Earth
- The core is very dense (1 teaspoon would weigh 5 tons)
- Higher mass white dwarfs are smaller

White dwarfs: Radius decreases with Mass

White Dwarfs

In Main Sequence Stars, the energy created by fusion drives the particles which create a pressure that holds the star up from the gravity of its outer layers.

But a white dwarf has no fusion occurring in its core.

What holds a white dwarf up?
The White Dwarf Limit

- Electrons move faster as they are squeezed into a smaller space.
- As a white dwarf’s mass approaches 1.4 solar masses, its electrons move at nearly the speed of light!
- This speed creates a pressure called electron degeneracy pressure.
- Because nothing can move faster than light, a white dwarf cannot be more massive than 1.4M_{\odot}, the white dwarf limit (or Chandrasekhar limit).

Class Action!

The event that marks the end of a star’s evolutionary life before becoming a white dwarf is

(A) a nova.
(B) a planetary nebula.
(C) the exhaustion of hydrogen in the core.
(D) a helium flash.

Class Action!

Which curve below shows the correct radius versus mass relationship for white dwarfs?

- (A)
- (B)
- (C)
- (D)
- (E)
Lightweight Stars (0.8 – 8 solar Masses)

3. Runs out of Helium
Becomes a White Dwarf

Image of white dwarf Sirus A, taken with the Hubble Space Telescope

Class Action!
The block diagram below summarizes the major stages of stars with masses similar to the sun. In which stage is the most helium produced through nucleosynthesis?

Proto Star → Main Sequence → Red Giant → Yellow Giant
Red Giant → Planetary Nebula → White Dwarf

Class Action!
The block diagram below summarizes the major stages of stars with masses similar to the sun. In which stage is the star the largest?

Proto Star → Main Sequence → Red Giant → Yellow Giant
Red Giant → Planetary Nebula → White Dwarf
Lecture Tutorial

• Break up into groups of 2-3
  – NO MORE THAN 3
• In your group, work through the following:
  – Binary Stars (pages 113-116)
  – Discuss the answers – don’t be silent!
• I will be roaming around if you need help…
• If your group finishes, check your answers with another group

Summary

• Hertzsprung-Russell Diagram: evolutionary tracks for stars based on an ensemble of observed stars.
• lightweight stars (0.8 – 8 solar masses):
  main sequence (H fusion) => red giant (He fusion)
  => planetary nebula => white dwarf

(not to scale)